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The American Journal of Alternative Agriculture provides an international forum for original research articles on the biological, physical, social science and policy aspects of alternative agriculture. The journal particularly focuses on multidisciplinary studies and covers the character and potential of alternative, sustainable and organic farming systems.

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AMERICAN JOURNAL OF ALTERNATIVE AGRICULTURE

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Editorial

As most of our readers should know by now, 2002 marks the start of an exciting new era for the *AJAA*, as CABI *Publishing* takes on the ownership and publication of the journal from its founders, the Henry A Wallace Center for Agricultural & Environmental Policy at Winrock International.

As you can see, we have already instituted some changes to the journal, in changing the journal cover and changing slightly the layout of the articles.

However, we will be striving to maintain the very high standards attained by the journal Editors during the first 16 years of its life.

We are delighted to announce that Bob Papendick is continuing as Editor of the *AJAA* during 2002, where he will provide a useful continuity between the old and the new publishers.

Both of us and our colleagues at CABI *Publishing* are delighted that the staff of the Henry A Wallace Center for Agricultural & Environmental Policy at Winrock International will continue to advise us on the scope and vision of the journal on an ad hoc basis.

Feedback is important to us during this time of change, so please let us know your thoughts on the journal, and what you want from it (contact details below). In addition, please submit your papers to us for publication (the Guide for Authors is printed at the back of this issue, with a more detailed version available at http://www.cabi-publishing.org/journals/ajaa), and continue to read and enjoy our journal.

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The relationship between soil quality and crop productivity across three tillage systems in south central Honduras

Melissa A. Stine and Ray R. Weil

Abstract. *Agricultural soil quality (SQ) research has focused on the influence of individual soil properties, particularly those related to soil organic matter (SOM), on soil processes such as water movement and retention, and nutrient cycling. However few studies have assessed the influence of these SOM-related properties on crop productivity, particularly under different management systems. Furthermore, agricultural SQ research in tropical regions is limited. The objectives of this study were, for a tropical site, to determine (1) the relationship between selected soil characteristics and resulting soil functional properties such as aggregate stability and porosity, and (2) the relationship between SQ indicators and productivity of corn under three different tillage systems. Twelve plots were randomly demarcated in three adjacent fields under different tillage systems. Profiles were described by augering and the surface soil (0–7.5 cm) was sampled just prior to crop harvest and analyzed for texture, standard soil tests (pH, available P, K, Mg and Ca) and SQ parameters including total N, total and active fraction C, porosity and aggregate stability. Corn dry grain m^{-2}, above-ground crop dry matter m^{-2}, and dry grain per plant was measured in each plot. Soil C parameters were highly predictive of macroaggregate stability and soil porosity across different tillage systems. Macroaggregate stability and soil C (particularly active C oxidizable by 0.025 m $KMnO_4$) were highly correlated with crop productivity across tillage systems. These findings suggest that soil C in the surface layer, especially the active C fraction, markedly affected the productivity of this tropical soil through its influence on soil structure.*

Key words: active soil carbon, minimum tillage, no-till, permanganate-oxidizable carbon, soil aggregate stability, soil organic matter, soil porosity, soil quality indicators, tropical agriculture

Introduction

The quality or health of a soil refers not only to its lack of degradation or contamination, but also to its overall fitness, or effectiveness for supporting plant growth, managing water and responding to environmental stresses (Lewandowski et al., 1999). In recent years soil quality (SQ) research has focused on the linkages among: (1) management practices and systems; (2) observable soil characteristics; (3) soil processes; and (4) performance of soil functions (Lewandowski et al., 1999). Soil organic matter (SOM)-related properties have been shown to serve as good SQ indicators (Arshad and Coen, 1992; Islam and Weil, 2000; Kennedy and Papendick, 1995; Larson and Pierce, 1994; Wander and Bollero, 1999). Soil organic matter is associated with reduced erosion and runoff, and improved infiltration, movement and retention of water in soil; soil aggregation; and nutrient cycling (Greenland and Szabolcs, 1994; Woomer and Swift, 1994). A microbially active C fraction, although a small component of the total SOM, plays a particularly important role in maintaining SQ (Weil, 1992). Active soil C regulates nutrient cycling (Gunapala and Scow 1998) and serves as an agent for building soil structure (Tisdal and Oades, 1982).

Research during the past 50 years has placed much emphasis on the importance of mineral nutrients for crop productivity with notably less research on the crop productivity effects o SOM management. While the beneficial effects of SOM management on soil functions have been well researched (Karlen et al., 1992; Seybold et al., 1996), it is more difficul to demonstrate the influence of SOM on crop yields (Lucas et al. 1977; Strickling, 1975). One reason for this difficulty is tha SOM levels are usually related to climate, topography and soi texture. Where crop productivity is compared across widely differing soils, the yield effects of these environmental factor tend to obscure or be confounded with those due to SOM level themselves. Furthermore, where differences in SOM ar achieved by imposing treatments such as different rotations tillage systems or rates of manure application, the SOM effect on crop yields are usually confounded with other effects of these treatments, such as the nutritional effect of high N legum residues, the water and temperature alterations due to surfac mulch, and the effect of N and other essential element contained in applied manure. Strickling (1975) was successfu

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in isolating the effect of organic C by imposing various crop rotations for two decades to alter soil C levels and then treating all plots alike in the final years (including adequate mineral fertilization) to assess the residual effects of the build-up or depletion of soil C. He found that SOM levels accounted for 82–84% of the variation in corn (*Zea mays* L.) yield regardless of level of N fertilization. He attributed the SOM effects on yield to enhancement of water infiltration resulting from improved aggregation.

The majority of SQ research has been conducted on temperate region soils; SQ research on tropical soils is much more limited (Ericksen and McSweeney, 2000; Palm et al., 1996). Woomer et al. (2001) reported that total organic C in soils accounted for 25% and active fraction C (particulate organic matter) accounted for 59% of the variation in corn yields on a highly weathered soil in the highlands of central Kenya.

The objectives of this study were to determine, for a tropical site: (1) the relationship among selected individual soil C characteristics and resulting soil functional properties, such as aggregate stability and porosity; and (2) the relationship between SQ indicators and productivity of corn ('Guayape') across three different tillage systems.

Materials and Methods

Study site

Soil quality properties and corn yields were measured in three adjacent 2.5–ha fields that had been converted from an 8–ha grass pasture using three different tillage systems. The fields were located on Potrero #3 in the Las Vegas section of the Pan American School of Agriculture (EAP) in Zamorano valley. This valley is located in the Department of Francisco Morazán, south central Honduras, at 13°55′N latitude and 86°57′W longitude, and at approximately 800 m above sea level. The average annual rainfall is 1132 mm and the average annual temperature is 18°C (Jirón Estrada, 1997; SPCP, 1989). Soils in the Zamorano valley formed on alluvial deposits that date back to the Quaternary period (11,000–1.7 million years ago) and contain sediment derived from igneous and basaltic rocks originating in the surrounding mountains (IGN, 1996; SPCP, 1989). The soil at the experimental site is classified in the Buffalo series: a medium-fine, mixed, isohyperthermic Vertic Haplustalf (USDA taxonomy) with poor drainage and a dark brown surface horizon approximately 20 cm thick (SPCP, 1989). The site is nearly level (0–2% slope) and prone to flooding. Borings were made with a bucket auger at seven locations in a transect across the Potrero fields and a sandy loam (10–15% clay) E horizon was observed to have an upper boundary varying from 18 to 33 cm. A Bt horizon with expanding-type clays (45–50% clay) began at 25–38 cm in depth. A few iron and manganese nodules were observed at depths greater than 34 cm, but without any discernable pattern along the transect. Soil pH increased with depth from 5.8–6.0 in the Ap horizon to 7.0–8.0 in the Bt.

Experimental design and sampling scheme

The site was in pasture dominated by stargrass (*Cynodon nlemfuensis* Vanderyst) for 25 years before it was converted to crop production beginning in 1995 (P. Paz, EAP, personal communication, January 2000). Before crops were planted, the field was divided into three smaller fields (approximately 2.5 ha each), and a composite soil sample was taken from each field to a depth of 30 cm. All three fields were then subsoiled to a depth of 24 cm to break up compacted layers attributed to trampling by cattle. Subsequently, glyphosate [*N*-(phosphonomethyl)glycine] was applied to the entire experimental area at a rate of 900 g a.i. ha^{-1}. Fifteen days later, the three fields were prepared for cropping by no-tillage (direct seeded), minimum tillage (chisel plow) and conventional tillage (moldboard plow and disc) methods, respectively. The no-till field was located nearest the road and was at a slightly higher elevation than the field under conventional till, which was nearest a stream. The field under minimum till was situated between the no-till and conventional till fields. Corn was mechanically planted on each field at 53,000 plants ha^{-1} in 1995, 1996 and 1998. Sorghum [*Sorghum bicolor* (L.) Moench] was planted in 1997. Corn stover was left in the field after grain harvest, but sorghum residue was removed for silage. The three fields were left fallow from November to June each year, resulting in substantial growth of volunteer stargrass that was killed by annual use of glyphosate before planting. For the 1998 cropping season, paraquat (1,1′-dimethyl 4,4′-bipyridinium), alachlor [2–chloro-*N*-(2,6–diethylphenyl)-*N*-(methoxymethyl)acetamide] and atrazine [6–chloro-*N*-ethyl-*N*′-(1–methylethyl)–1,3,5–triazine–2,4–diamine] herbicides were applied at the time of planting, at rates of 1200 g a.i. ha^{-1}, 960 g a.i. ha^{-1} and 252 g a.i. ha^{-1}, respectively. Diammonium phosphate fertilizer was applied at planting (29 kg N ha^{-1} and 32 kg P ha^{-1}) and urea was applied 1 month after planting (84 kg N ha^{-1}).

In October 1998 four 4 × 2–m sampling plots were demarcated at random locations within each of the three fields, for a total of 12 sampling units. Since tillage methods were spatially segregated into adjacent fields, there were no independent replicates within a tillage method (Hurlbert, 1984). Such systematic experimental designs risk introducing bias to treatment effects (e.g., a gradient in soil depth or drainage), which may lead to type I errors (Hulbert, 1984; Yates, 1939). Therefore, inferences about effects of tillage methods cannot be made from this study with a known level of statistical confidence.

Data collection

The surface soil in each plot was described and 12 cores, sampled to a depth of 7.5 cm, were combined to make a composite sample for each plot. Soils were sampled in 1998 just prior to harvest, when the soil was least likely to have been recently disturbed. This sampling depth was chosen as the layer in which major differences among tillage practices generally first occur (Mielke et al., 1986). Soil parameters measured in the field were depth of A horizon, color (A horizon and underlying horizon) and texture by feel (A horizon and underlying horizon).

Laboratory analysis of surface soil samples included the following tests. Anthrone-reactive carbohydrate C (ARC) was measured on fresh samples using a modification of Brink et al. (1960), whereby the soil was extracted with 0.5 *M* K_2SO_4 after microwave irradiation (Islam and Weil, 1998). Carbon oxidizable by dilute permanganate (C_{OXID}) was determined by shaking 1 g air-dried soil in 20 ml of 0.025 *M* $KMnO_4$ for 15 minutes, followed by centrifugation to clear the supernatant, and measurement of light absorbance at 550 nm [modified by Islam and Weil (1999), from the 0.33 *M* $KMnO_4$ method of Blair et al. (1995)]. Total C (C_{TOT}), total N (N_{TOT}) and total H (H_{TOT}) were determined by high temperature combustion using LECO CHN-600 analyzer (LECO Corp., St. Joseph, Mich.). The stability of 1–4 mm macroaggregates (AGG) was determined by a modification of Kemper and Rosenau (1986) method. The University of Maryland Soil Testing Laboratory determined Mehlich I extractable P, K, Mg and Ca. Particle size distribution was determined by a pipette method (Weil, unpublished data); porosity was calculated from the bulk density of 12 cores; and pH (in water and in 1 *M* KCl) was measured using a combination glass/calomel electrode. Effective cation exchange capacity (ECEC) was estimated as the sum of the mol charge kg^{-1} from K, Mg and Ca, plus exchangeable acidity, as measured by pH_{KCl}.

All corn stalks and ears within each 4 × 2–m plot were counted and weighed in the field. Three plants and three ears were also randomly selected from each plot and the fresh and dry weights were obtained. Crop productivity was calculated as dry grain m^{-2}, above-ground crop dry matter m^{-2} and dry grain per plant.

Statistical methods

SYSTAT statistical software (SPSS, 1997) was used for all statistical analyses. Soil properties were plotted against each other and against crop productivity variables to determine the nature of these relationships. Linear regression was used to determine the relationship among three measures of soil C. Forward stepwise multiple regression was used to determine possible combinations of soil variables most associated with soil macroaggregate stability and soil porosity. The significance level for each variable to enter the model and stay was 0.05. The best-fit line was then determined between the soil variables that remained in the model and the soil functional properties. Pearson correlation and linear regression were used to express relationships between individual soil properties and crop productivity. Forward stepwise multiple regression was used to test a suite of soil variables against crop productivity, with the aim of developing a soil quality model that would best predict crop yield. The significance level for each variable to enter this model was 0.15 and the significance level to stay in the model was 0.05.

Table 1. Soil properties (0–7.5 cm layer) and corn yields in 1998 in three adjacent fields cropped for 4 years under different tillage systems (mean ± standard error, $n = 4$).

Measured variable	Upper field under no tillage	Middle field under minimum tillage	Lower field under conventional tillage
Soil properties		Mean ± standard error	
ARC (g kg^{-1} soil)	0.228 ± 0.01	0.157 ± 0.004	0.101 ± 0.007
C_{OXID} (g kg^{-1} soil)	2.17 ± 0.140	1.54 ± 0.080	1.23 ± 0.054
C_{TOT} (g kg^{-1} soil)	35.6 ± 1.51	24.4 ± 0.85	17.9 ± 0.40
ARC:C_{TOT}	0.64 ± 0.008	0.65 ± 0.02	0.56 ± 0.05
C_{OXID}:C_{TOT}	6.1 ± 0.2	6.3 ± 0.2	6.8 ± 0.2
AGG (%)	14.1 ± 2.3	4.72 ± 0.28	3.54 ± 0.24
C_{TOT}:N_{TOT}	10.9 ± 0.12	10.7 ± 0.20	10.4 ± 0.21
N_{TOT} (g kg^{-1} soil)	3.27 ± 0.17	2.28 ± 0.05	1.73 ± 0.02
P (kg ha^{-1})[1]	116.5 ± 10.7	99.26 ± 11.6	83.75 ± 39.8
K (kg ha^{-1})[2]	390.4 ± 28.0	291.2 ± 20.7	229.6 ± 20.7
Ca (kg ha^{-1})[3]	2390 ± 640	2339 ± 783	2296 ± 204
Mg (kg ha^{-1})[4]	303.7 ± 20.0	293.1 ± 20	347.3 ± 11
pH_{water}	5.25 ± 0.087	5.30 ± 0.058	5.38 ± 0.14
pH_{KCl}	4.72 ± 0.11	4.75 ± 0.065	4.58 ± 0.12
ECEC (cmol kg^{-1})	6.91 ± 0.47	6.64 ± 0.59	6.38 ± 0.50
Porosity (%)	64.8 ± 0.77	61.5 ± 1.22	59.2 ± 1.3
Corn properties			
Grain (g m^{-2})	537 ± 74	333 ± 64	207 ± 33
Dry matter (g m^{-2})	2014 ± 273	1503 ± 152	1244 ± 222

[1] P test levels are as follows: low = 14–29, medium = 30–49, high = 50–99, very high = >99.
[2] K test levels are as follows: low = 34–78, medium = 79–149, high = 150–299, very high = >299.
[3] Ca test levels are as follows: low = 0–480, medium = 481–963, high = 964–1926, very high = >1926.
[4] Mg test levels are as follows: low = 40–78, medium = 79–139, high = 140–297, very high = >297.
[Ranges calculated from Coale (1996), as determined for soils in the south-eastern US.]
For the soil properties: ARC = anthrone-reactive carbohydrate C, C_{OXID} = C oxidizable by dilute permanganate, C_{TOT} = total C, AGG = 1–4 mm soil macroaggregates, N_{TOT} = total N, and ECEC = effective cation exchange capacity.

Results and Discussion

Relationships among soil properties under three tillage systems

Soil properties and corn productivity measures for each of the three fields are presented in Table 1. Surface soils in the upper field under the no-till system were higher in SQ parameters and macronutrients compared to the middle and lower fields under the minimum and conventional tillage systems, respectively. Similar trends were observed with respect to crop productivity among the fields. These differences in SQ and crop productivity cannot be strictly ascribed to tillage, however, because true replication of tillage treatments and proper baseline data were lacking. Instead, they could have resulted from subtle soil drainage differences or other pre-existing factors that we failed to observe.

The active soil C fraction (as measured by C_{OXID} and ARC) was highly correlated with C_{TOT} across all three fields (Fig. 1). The no-till field was highest in both total C and active C, while the conventional till field was lowest in both total and active C. The strong correlation between the active C fractions and C_{TOT} across a range of values suggests that the change in C_{TOT} resulted from proportional changes in both the active and passive C fractions. This interpretation is supported by the nearly constant ratios of C_{OXID} or ARC to C_{TOT} across fields. In contrast, other researchers (e.g., Cambardella and Elliott, 1992), working in temperate regions, have reported that cultivation of grassland soils has impact primarily on the active C fractions, reducing the ratio of active fraction C to total C even as total C declines. The C content differences in the upper 7.5 cm among fields may have been partially due to differences in the extent to which the three tillage systems mixed the high C surface layer with the lower C soil below.

It was hypothesized that active C levels, as measured by C_{OXID} and ARC, would explain much of the variability in macroaggregate stability across the three fields. Forward stepwise multiple regression was used to examine possible combined effects on macroaggregate stability of the following soil properties: C_{OXID}, ARC, C_{TOT}, N_{TOT}, P, K, pH_{KCl}, Ca and Mg. While each of the first four variables listed exhibited a significant correlation with macroaggregate stability, C_{OXID} had the highest correlation coefficient and was the only variable found to remain in the final model for aggregate stability ($F = 50.6$, $P < 0.0001$). This result supports the role of the labile C components in macroaggregation and the value of C_{OXID} as a measure of active C.

The best-fit model of the relationship between C_{OXID} and macroaggregate stability (Fig. 2a) suggests that C_{OXID} below a threshold level of approximately 1750 g kg^{-1} did not appear to have an effect on macroaggregate stability, while small increases in C_{OXID} above this threshold level were reflected in up to a fourfold increase in macroaggregate stability. Macroaggregate stability was highest in the no-till field and lowest in the conventional till field, but overall macroaggregate stability levels were relatively low across all three fields. Low levels of macroaggregate stability are typical of soils dominated by 2:1

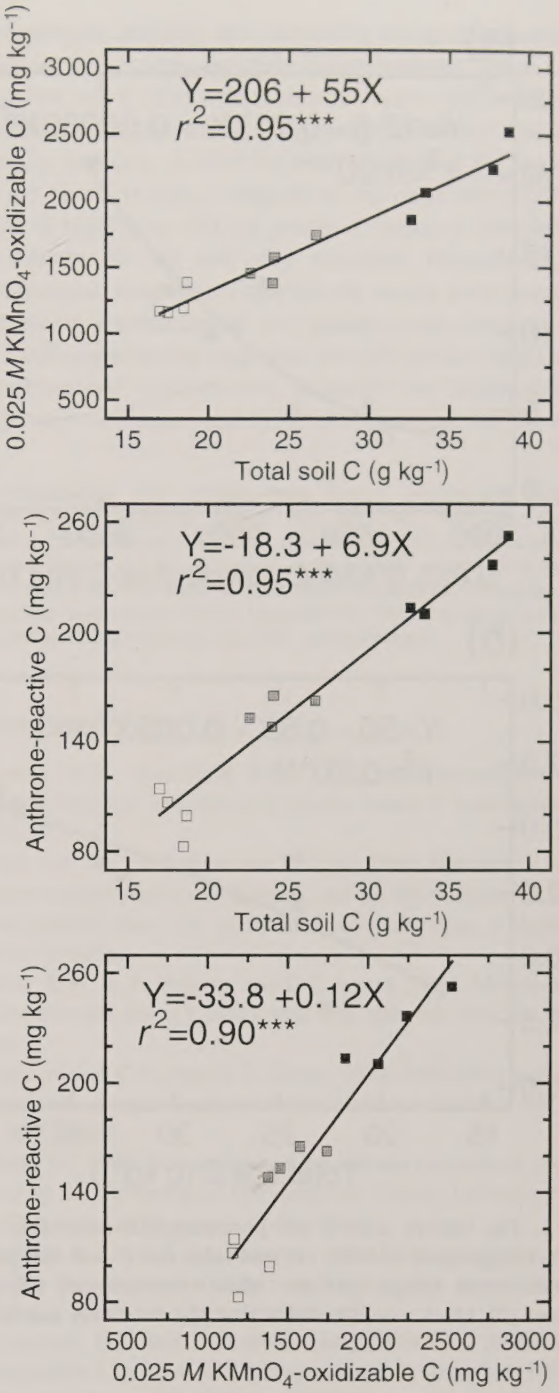

Figure 1. The relationships among three measures of soil C across three tillage systems (white = conventional till, gray = minimum till, black = no till); $n = 12$. ***Significant at the 0.001 level of probability. Note that the axes do not begin at zero.

expanding-type clays. It is not known if the relationship between macroaggregate stability and C_{OXID} observed in this study exists in more strongly aggregated soils.

Using forward stepwise multiple regression, C_{TOT} was the only measured soil variable that remained in the final model to predict soil porosity ($F = 23.1$, $P < 0.001$). This finding also supports the idea that soil C is an important factor influencing

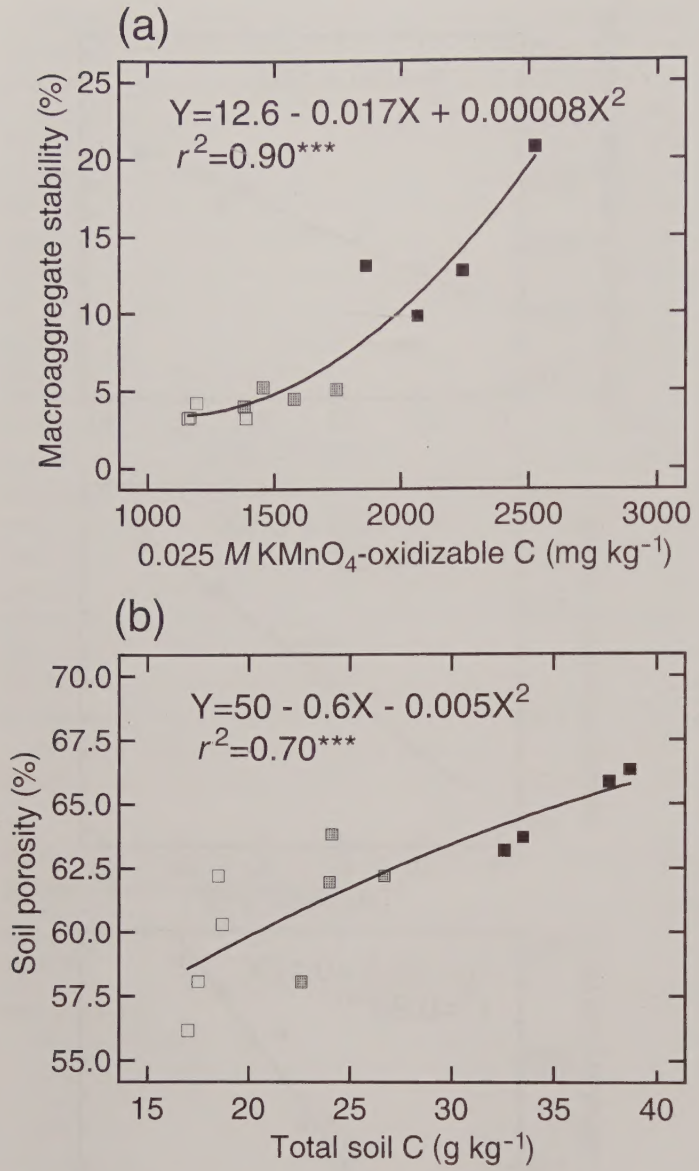

Figure 2. The best-fit models for permanganate-oxidizable soil C and macroaggregate stability (a) and total soil C and soil porosity (b) across three tillage systems (white = conventional till, gray = minimum till, black = no till). Note that the axes may not begin at zero.

soil functional properties such as porosity (and its inverse, bulk density). The relationship between C_{TOT} and porosity fits a quadratic model, as illustrated in Figure 2b. Both macroaggregate stability and porosity in the upper 7.5 cm of soil have the potential to affect crop productivity through their influence on water infiltration and aeration.

Relationship between soil quality and crop productivity under different tillage systems

Comparison of individual soil properties with crop productivity revealed that C-related soil properties were highly correlated with corn grain yield across three tillage systems (Table 2).

Table 2. Pearson correlation coefficients (r) between soil and crop yield variables across three tillage systems ($n = 12$).

	Measures of crop productivity	
Measured soil property[1]	**Grain yield ($g\ m^{-2}$)**	**Crop dry matter ($g\ m^{-2}$)**
AGG (%)	0.87****	0.76***
C_{OXID} ($g\ kg^{-1}$)	0.86****	0.76***
C_{TOT} ($g\ kg^{-1}$)	0.83***	0.72**
N_{TOT} ($g\ kg^{-1}$)	0.83***	0.73**
K ($kg\ ha^{-1}$)	0.83***	0.81***
ARC ($g\ kg^{-1}$)	0.81***	0.70*
pH ($pH_{water} - pH_{KCl}$)	0.75**	NS
C_{TOT} :clay	0.68*	0.69*
Porosity (%)	0.64*	0.66*
pH_{KCl}	NS	0.66*
Ca ($kg\ ha^{-1}$)	NS	NS
ECEC ($cmol\ kg^{-1}$)	NS	NS
C_{TOT}:N_{TOT}	NS	NS
P ($kg\ ha^{-1}$)	NS	NS
Mg ($kg\ ha^{-1}$)	NS	NS
pH_{water}	NS	NS

*,**,***,**** Significant at the 0.05, 0.01, 0.001 and 0.0001 levels of probability, respectively.
[1] See Table 1 for description of soil properties.

Macroaggregate stability was the soil variable most closely correlated with yield, but ARC, C_{OXID} and C_{TOT} were also highly correlated. Similar trends were observed between soil properties and above-ground crop dry matter. Both the grain and stover had matured before Hurricane Mitch arrived in late October/early November 1998; however, as harvest took place under wet, muddy conditions following flooding from the hurricane, the stover data may have been affected by soil contamination. The grain, on the other hand, was held in the ear high enough off the ground to escape any soil contamination.

Properties relating to soil fertility were less correlated or unrelated to corn yields. Since all three fields in this study had relatively high N, P and K availability, these nutrients were not expected to be limiting factors in plant growth or to play major roles in yield variability. The correlation between yield and K shown in Table 2, rather than suggesting that K caused the higher yields, is more likely to be a result of vegetative 'pumping' of K (Vilela and Ritchey, 1985) that may have brought additional K to the soil surface, where it would have remained relatively undisturbed in the no-till plots.

The following soil variables were included in a forward stepwise multiple regression model on grain yield: C_{TOT}, N_{TOT}, P, K, pH_{KCl}, Ca, Mg, AGG, C_{OXID} and ARC. Macroaggregate stability (AGG) was the only variable found to be significant and remain in the final model ($F = 31.5$, $P < 0.0001$). Thus, macroaggregate stability appeared to be the best predictor of soil productivity under three tillage systems. Furthermore, Figure shows that there is a positive relationship between AGG and grain yield, and between C_{OXID} and grain yield. The data confirm therefore that active soil C, and related functional soil

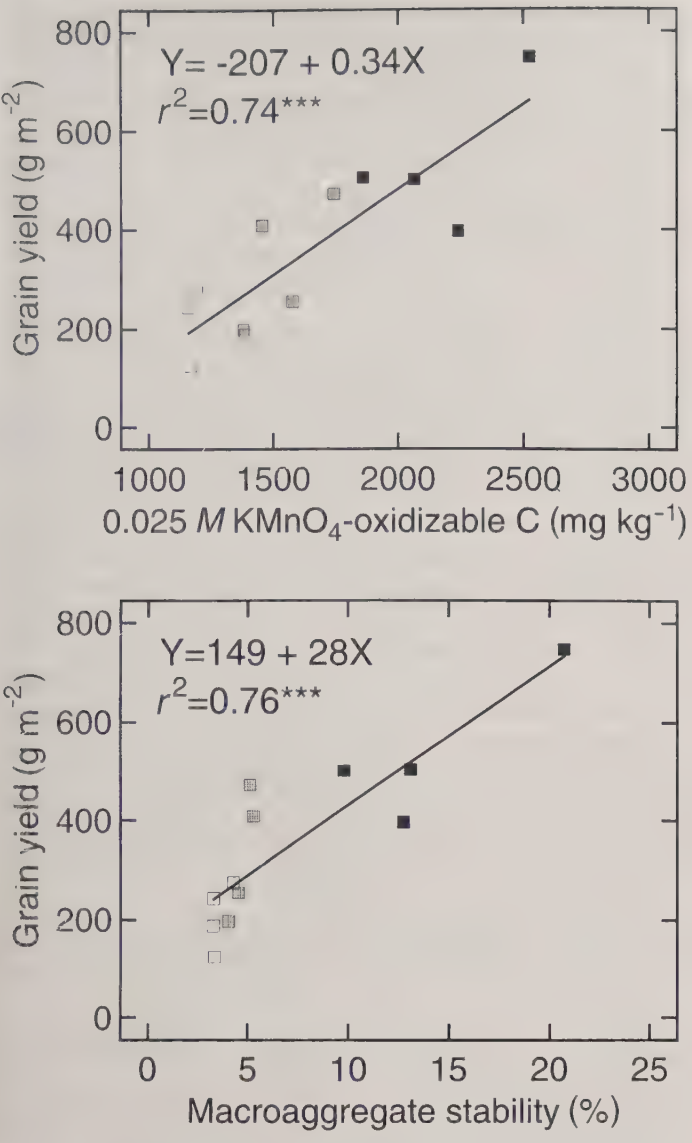

Figure 3. The relationship between soil quality properties and corn grain yield across three tillage systems (white = conventional till, gray = minimum till, black = no till, $n = 12$). ***Significant at the 0.001 level of probability. Note that the axes may not begin at zero.

variables such as soil aggregation, play important roles in improving SQ for crop production. We speculate that increased C_{OXID} may have influenced corn yields through its effect on aggregation, which in turn may have improved the capture of rainwater. Unfortunately, it is not possible to determine from the data obtained whether improved soil quality enhanced corn yield, or whether high plant production caused the improvements in soil C–related properties.

Conclusions

Soil C was strongly correlated with two soil functional properties, i.e., macroaggregate stability and soil porosity across fields under three different tillage systems. Soil C, as well as macroaggregate stability, also showed a strong relationship with crop productivity across the three tillage systems. These findings suggest that soil C, and particularly the active soil C fraction, is important to soil functioning and plant productivity. Soil quality parameters and crop productivity were higher in the upper field under the no-till system, compared to the other two tilled fields, but lack of replication did not permit a statistical comparison of tillage effects on soil and crop variables. Properly designed, well-replicated, long-term experiments would have great value in promoting knowledge of soil quality under tropical conditions. Such experiments may also provide greater opportunities for international collaborative research on sustainable land management techniques and systems appropriate for the tropics.

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Soil-test dynamics throughout a five-year 'Thompson Farm' rotation in Iowa

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Abstract. *Soil-testing is an effective guide for achieving and maintaining an optimum supply of available plant nutrients, but there is little information on the multi-year soil-test changes for farms using long-term crop rotations, ridge-tillage and nutrients supplied by a mixture of organic amendments. Our objectives were to characterize yearly changes in surface soil-test parameters, including the stratification of P and K; compare soil-test methods (Mehlich III versus Bray P1 and 1 M NH_4OAc exchangeable K); and evaluate soil-test interpretation strategies [sufficiency level versus basic cation saturation ratio (BCSR)] within a farmer-managed field. The study was conducted on the Clarion–Nicollet–Webster Soil Association near Boone, IA, in a field that had not been moldboard plowed for 29 years. Soil samples were collected from the 0–5, 5–10, 10–15, and 15–20 cm depth increments before plowing and every autumn thereafter throughout the 5-year rotation. Samples were analyzed for pH, Bray extractable P, exchangeable K, total C and N, NH_4- and NO_3-N concentrations, and Mehlich III extractable P, K, Ca, Mg, Na, Mn and Zn. Stratification of P and K was evident within 2 years after moldboard plowing. This was not considered a production problem, because, based on sufficiency-level soil-test interpretations, the animal manure/municipal sludge applications had increased soil P and K concentrations to levels where no crop response to additional fertilizer would be expected. Using Mehlich III extractant with simultaneous inductively coupled plasma–atomic emission spectrometer (ICP–AES) analysis resulted in soil-test interpretations that were the same as with Bray P1 and 1 M ammonium acetate (NH_4OAc) extracting solutions. The Mehlich III solution did extract more Ca than 1 M NH_4OAc, causing K saturation percentages to be very low when the data were interpreted using a BCSR approach. We conclude that stratification is not a production issue at this site; that either soil-test methodology would be acceptable for P and K extraction; and that additional studies evaluating the BCSR soil-test interpretation philosophy are warranted.*

Key words: ridge-tillage, basic cation saturation ratio, organic amendments, nutrient stratification

Introduction

Developing farmer–researcher partnerships and conducting on-farm studies are two of the most effective ways to understand the soil, plant, environment and human relationships that are required to ensure that an agricultural production system is, and can remain, sustainable. One example of a successful partnership is that which has evolved between the US Department of Agriculture–Agricultural Research Service-National Soil Tilth Laboratory (USDA–ARS–NSTL) and Richard and Sharon Thompson (Thompson Farm) of Boone, Iowa. Previous studies have included farming system evaluations (Karlen et al., 1995), spatial soil fertility analysis (Cambardella and Karlen, 1999), and weed seed bank dynamics (Buhler et al., 2001). Each successive study has inevitably led to other questions. Those emerging most recently have focused on the soil-test dynamics associated with the Thompson Farm 5–year crop rotation. Questions regarding phosphorus (P) and potassium (K) stratification, soil-test methodologies and interpretation philosophies were among those raised most frequently.

With regard to P and K stratification, Richard Thompson, our farmer cooperator was concerned that producers were often given mixed messages regarding its importance in ridge-tillage or no-tillage systems. He was aware that stratification increased nutrient concentrations near the soil surface, that the concentrations declined rapidly with depth (Holanda et al., 1998), and that surface fertilizer application is often cited as the cause for stratification of P. He was not sure if his production practices, which included incorporation of a manure/municipal sludge mixture during 2 or 3 years of every 5–year rotation, were affecting stratification in the same way as has been shown in studies with broadcast commercial fertilizer. However, periodic soil testing had shown higher P and K concentrations in the surface 5 cm than at lower depths (15–20 cm), and on-farm research trials had shown some corn (*Zea mays* L.) response to banding or deep placement of P and K fertilizers (Thompson et al., 2000). Based on those experiences, he thought that periodic moldboard plowing might eliminate the stratification and be beneficial for his long-term crop yields.

In addition to the observed stratification, ridge-tillage, a management practice associated with K deficiencies in the northern Corn Belt (Allan et al., 1992; Rehm and Fixen, 1990), was being used for the row crops in this field. This added to our

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cooperator's concern because ridge-tillage studies have shown K deficiencies, even on soils with high to very high soil-test K values. Several factors, including increased compaction, changes in root density and elongation rates among hybrids (Allan et al., 1999), lower soil temperature and reduced aeration because of increased soil bulk density, are among some that may be involved. Robbins and Voss (1991) concluded that yield-limiting problems could develop with ridge-tillage and other reduced-tillage practices due to the positional unavailability of plant nutrients. They suggested that to minimize nutrient availability problems, producers should (1) build P and K to non-limiting levels before initiating ridge tillage, (2) knife P and K between ridges at a 15–20 cm depth as needed, or (3) apply a starter band of fertilizer 5–7 cm deep and 5–7 cm to the side of each crop row.

The choice of soil-test methodology, specifically which extracting solution should be used, was another question that arose. The predominant extracting solutions for central-Iowa soils are the Bray/Kurtz P1 extractant for P and 1 *M* ammonium acetate (NH_4OAc) for exchangeable K. However, an increasing number of soil-test laboratories are switching to a more universal extractant, such as Mehlich III (Mehlich, 1984), because it is a multi-element soil extraction solution that offers increased convenience for the soil-testing operations (Hanlon and Johnson, 1984). A previous study correlating P extraction from 350 soil samples, and calibrating the levels based on 61 field response trials (Mallarino, 1997), suggested that Mehlich III was more reliable than Bray P1 for estimating plant-available P of Iowa soils over a broad range of soil pH and calcium carbonate equivalent (CCE). However, it was not evident in that study whether any of the samples represented sites within a long-term crop rotation where manure and municipal sludge were being used to provide the essential plant nutrients.

The third question was how to interpret the soil-test data. Currently there are three soil fertility management concepts (nutrient build-up and maintenance, cation saturation ratio and nutrient sufficiency level), which can result in different nutrient application recommendations based on the same soil-test data. The philosophies, discussed in detail by Olson et al. (1985), Eckert (1987), Rehm (1994) and Kelling et al. (1996), are summarized below to illustrate the dilemma that many producers encounter when seeking to understand soil-test interpretations and implement the most sustainable nutrient management practices on their farms.

The 'nutrient build-up and maintenance' philosophy focuses on correcting any nutrient deficiencies rapidly by raising soil-test concentrations to a level where crop yields are maximized, and then following with regular nutrient applications to maintain a non-limiting soil-test level. This philosophy, sometimes referred to as 'fertilizing the soil', is most applicable to low-mobility nutrients such as P and K. Shortcomings of this approach include cost, especially if the nutrients involved are subject to losses through volatilization, leaching, soil erosion or 'luxury consumption' by some crops within the rotation.

The basic cation saturation ratio (BCSR) evolved from work by Bear and Prince (1945), emphasizing that maximum crop yields can only be achieved by creating an ideal ratio of calcium (Ca), magnesium (Mg) and K. According to Eckert (1987), Bear and Prince concluded that the ideal soil would provide 65% Ca, 10% Mg, 5% K and 20% hydrogen (H) on the cation exchange sites. These cation saturation percentages were derived from approximately 8 years of research with alfalfa (*Medicago sativa* L.) on New Jersey soils. The BCSR concept was modified somewhat by Graham (1959), who proposed saturation ranges of 65–85% Ca, 6–12% Mg and 2–5% K for Missouri soils. These ranges in cation saturation percentages allow for rather wide variations in actual Ca/Mg/K ratios in the soil, and thus have contributed to the confusion associated with the BCSR philosophy. In fact, the concept of an 'ideal ratio' has never been verified, and a review of the original work suggests that the ideal ratio was based as much on economic considerations as agronomic requirements for optimum plant growth (Eckert, 1987).

The 'sufficiency level' philosophy assumes that an optimum level for each nutrient can be defined and results in soil ratings that range from 'very low' to 'very high' (Olson et al., 1985). Below the defined sufficiency level, crops will respond to inputs, but if soil-test levels are above the defined optimum, crops are not expected to respond to additional applications. The critical assumption is that a sufficiency level can be defined for each nutrient.

To help answer these farmer-generated soil-test questions, we agreed to monitor pH and nutrient changes for a predominant soil within a single production-scale field throughout a complete 5-year crop rotation cycle. Our specific objectives were to (1) characterize yearly dynamics in surface soil-test parameters; (2) compare Mehlich III versus Bray P1 and 1 *M* NH_4OAc exchangeable K soil-test methods; and (3) examine how sufficiency level versus BSCR interpretation strategies could affect soil-test interpretations.

Materials and Methods

A field experiment was conducted on Nicollet loam (fine-loamy, mixed mesic Aquic Hapludolls) from October 1994 through October 1998 on the Thompson Farm near Boone, Iowa. The field has been managed since at least 1967 in a 5-year crop rotation of legume/grass hay [alfalfa, alsike clover (*Trifolium hybridum* L.), red clover (*Trifolium pratense* Sibth.), orchard-grass (*Dactylis glomerata* L.) and timothy (*Phleum pratense* L.)], corn, soybean [*Glycine max* L. (Merr.)], corn and oat (*Avena sativa* L.), with the legume/grass forage mixture under-seeded (Table 1) with the oat crop (Karlen and Colvin, 1992). Since 1980, the corn and soybean were produced using a ridge-tillage system with disking prior to planting oats. Prior to this study, the site had not been moldboard plowed since 1965.

Tillage and fertility practices varied by year and crop (Table 1), although no commercial fertilizers or pesticides were used. Plant nutrients were provided to the corn crops by applying a mixture of animal manure and municipal sludge that had been accumulated in a concrete storage bunker (Thompson et al., 2000). The manure/sludge mixture for 1995 was applied after soil samples were collected but before the site was plowed

Table 1. Cropping practices used for Field No. 3 on the Thompson Farm near Boone, Iowa from 1993 through 1998.

Year/crop	Tillage and cultural practices	Manure applied
1993/oat	Disk twice in spring, plant oat and legume mixture	None
1994/hay	Moldboard plow in autumn, plant rye cover crop	18 Mg ha^{-1} dry matter (443–210–216 kg total N, P, and K ha^{-1}) prior to moldboard plowing
1995/corn	Disk twice in spring, plant corn, rotary hoe twice, two inter-row cultivations for weed control and ridge building, plant rye cover crop on ridges after corn harvest	None
1996/soybean	Ridges truncated during soybean planting, rotary hoe twice, two inter-row cultivations for weed control and ridge building, broadcast oat cover crop in standing soybean crop	None
1997/corn	Ridges truncated during corn planting, rotary hoe twice, two inter-row cultivations for weed control ridge building	9 Mg ha^{-1} dry matter (257–105–108 kg total N, P, and K ha^{-1}) in April
1998/oat	Disk twice in spring, plant oat and legume mixture	None

For 1997, the mixture was applied in the spring, 1 day before planting. The manure/sludge was then covered as the front planter sweeps moved soil from the top layer of the ridge. Soybean and corn were planted into the freshly scraped ridge during a single pass in 1996 and 1997, respectively. Weeds were controlled in the row crops by making two or three passes with a rotary hoe and two inter-row cultivations. Weeds were not considered to be a problem in the oat crop since they were cut and baled with the straw.

Four representative sampling sites for the Nicollet loam soil were selected within the 16 ha field. Each site was approximately 100 m^2 and was divided into three subsampling areas that were marked and sampled annually throughout the 5-year crop rotation. Ten soil cores (5 cm diameter by 20 cm deep) were collected in October of each year in a M-shaped pattern from each of the subsampling areas. Each core was divided into increments of 0–5, 5–10, 10–15 and 15–20 cm and composited by depth. The samples were transported to the NSTL within 3 hours of sampling and stored at –5°C until analysis.

Each sample was air-dried and crushed to pass a 2–mm sieve. For each of the 5 years, Bray extractable P1 concentrations (Frank et al., 1998) were measured colorimetrically using ascorbic acid–ammonium molybdate reagents, and 1 *M* NH_4OAc exchangeable K (Warncke and Brown, 1998) was measured using emission spectrophotometry. Soil pH was determined using a soil-to-solution ratio of 1:1 in water. After checking for and removing free carbonates with sulfurous acid, total organic C and N were measured by dry combustion using a Carlo-Erba NA1500 NCS elemental analyzer (Haake Buchler Instruments, Paterson, NJ). Soil ammonium-N (NH_4-N) and nitrate-N (NO_3-N) concentrations in a 2 *M* KCl extract were determined using a flow-injection auto-analyzer (Lachat Instruments, Milwaukee, WI). For 1996 through 1998, soil samples were also extracted using a Mehlich III solution (Mehlich, 1984) and analyzed for P, K, Ca, Mg, sodium (Na), manganese (Mn) and zinc (Zn), using a simultaneous inductively coupled plasma–atomic emission spectrometer (ICP–AES) (Thermo Jarrell Ash, ICAP 61E, Franklin, MA).

The data were analyzed by year and using a split-plot experimental design, with time considered to be the whole plot and sampling depth the subplots. The 5 years of Bray and ammonium acetate data and 3 years of Mehlich III data were analyzed separately. Mean values were computed using data from three sampling sites in each of the four field replications prior to running analysis of variance (ANOVA) using SAS statistical software (SAS Institute, 1999). Main effects and interactions were tested for significance. Means were separated by Fisher's protected LSD test at $\alpha = 0.05$ using the appropriate error term based on significant main effects or interactions. Simple correlation and linear regression analyses were also performed using SAS software.

Results and Discussion

Soil pH, P and K stratification

Soil-test analyses throughout the 5-year study showed soil pH at all four depth increments to be very near 7.0 with the differences among depth increments being significant only in 1997 (Table 2). When averaged across the four depth increments (Table 3), the pH in 1997 was also significantly higher than in the other years. An analysis of the animal manure/municipal sludge mixture applied in the spring of 1997 (Thompson et al., 2000) showed the pH for that year to be 8.0 compared to 6.9 for the mixture that was applied in 1994. This was presumably responsible for the increase in soil pH measured in October 1997.

One of the primary concerns that prompted this study was the P and K stratification that was very evident prior to moldboard plowing in 1994 (Table 2). The application of the animal manure and municipal sludge mixture, followed by moldboard plowing (Table 1) eliminated most of the P stratification in the top 20 cm of the soil profile for 1 year (Table 2). However, within 2 years of moldboard plowing, P stratification was evident again and continued to increase as soil sampling continued throughout the 5-year crop rotation. Exchangeable K showed a similar pattern, with the animal manure/sludge mixture and moldboard plowing

Table 2. Yearly fluctuation in soil pH, Bray/Kurtz extractable P and exchangeable K for a Nicollet loam managed in a 5-year crop rotation on the Thompson Farm near Boone, Iowa.

	Year/crop				
	1994/hay	1995/corn	1996/soybean	1997/corn	1998/oat
Soil depth (cm)	pH (1:1)				
0–5	7.0	7.0	7.1	7.3	7.1
5–10	7.0	7.0	7.1	7.2	7.1
10–15	6.9	7.0	7.0	7.1	7.0
15–20	6.7	7.0	7.0	7.0	7.0
LSD (0.05)	NS[1]	NS	NS	0.1	NS
	Bray P (mg kg^{-1})				
0–5	104	68	93	134	122
5–10	77	67	88	108	88
10–15	29	66	76	99	62
15–20	17	54	66	87	49
LSD (0.05)	12	NS	13	22	23
	Exchangeable K (mg kg^{-1})				
0–5	180	180	214	345	287
5–10	122	156	163	238	141
10–15	111	165	154	204	110
15–20	114	158	160	192	103
LSD (0.05)	19	16	34	49	61

[1] NS = not significant.

Table 3. Average yearly soil-test P and K values for the surface 20 cm within a 5-year crop rotation field on the Thompson Farm near Boone, Iowa.

				Mehlich III extractable	
Year	pH	Bray P (mg kg^{-1})	Exchangeable K (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})
1994	6.9	57	132	–[1]	–
1995	7.0	64	165	–	–
1996	7.0	81	173	119	172
1997	7.2	107	245	142	205
1998	7.0	80	160	148	179
LSD (0.05)	0.2	14	36	NS[2]	NS

[1] Not measured

[2] NS = not significant.

reducing the differences between the surface 5 cm and the lower-depth increments for 1995. By October 1996, significant K stratification was evident again, continuing through the next 3 years of the rotation. The yearly soil-testing also showed that in addition to the recurrence of stratification, application of animal manure/municipal sludge prior to the 1997 crop (Table 1) significantly increased soil-test P and K levels at each depth increment (Tables 2 and 3). Only when oat grain and the straw plus an under-seeded forage crop were removed in 1998, did the soil-test P and K concentrations in the surface 20 cm begin to decrease (Table 3).

Using Iowa State University (ISU) soil-test interpretations to evaluate our soil-test P and K data was difficult because these ratings (very low, low, optimum, high, or very high) are for surface samples collected from 15–17.5 cm deep cores (Voss et al., 1999). Our samples were collected in 5 cm increments to a depth of 20 cm; so to overcome this limitation, we computed average values for the 0–15 cm depth (not shown) or for the surface 20 cm (Table 3). Incrementally, Bray P1 concentrations in the 0–5 cm increment were 2.3–4.5 times the ISU 'very high' level (>30 mg kg^{-1}). The 5–10 cm increment ranged from 2.2 to 3.6 times the 'very high' level, while the 10–15 cm increment ranged from 1 to 3 times that high (Table 2). Prior to moldboard plowing, Bray P at the 15–20 cm increment was in the medium or 'optimum' (16–20 mg kg^{-1}) range, but thereafter it was 1.6–2.9 times the 'very high' rating. The average Bray P for the surface 15 cm ranged from 67 to 114 mg kg^{-1}, or more than twice the ISU 'very high' soil-test P rating, while those for the surface 20 cm ranged from 57 to 107 mg kg^{-1} or 1.9–3.6 times the 'very high' rating. Based on these soil-test P levels, we do not consider the P stratification to be an agronomic problem within this field on the Thompson farm, even though it was detected through soil testing and the differences among depth increments were statistically significant. Our conclusion is based on extensive calibration data showing that when soil-test P levels are above 30 mg kg^{-1}, additional applications are simply not economical for crop production and can result in other plant nutrition (e.g., Zn deficiency) problems (Voss et al., 1999). If profile soil-test levels are not high, however, stratification can be a much more important problem.

Average exchangeable K concentrations for either the 0–15 cm depth (calculated from Table 2) or the 0–20 m depth (Table 3) were also consistently rated 'high' (131–170 mg kg^{-1}) or 'very high' (>171 mg kg^{-1}). Furthermore, with two exceptions (before the animal manure/sludge application and moldboard plowing in 1994, and after the 1997 oat crop) the exchangeable soil-test K concentrations at each sampling depth (Table 2) were also rated 'high' or 'very high'. Below the surface 5 cm in 1994 and below 10 cm in 1997, exchangeable K values were in the 'medium or optimum' (91–130 mg kg^{-1}) range (Voss et al., 1999). Based on the sufficiency-level philosophy of soil-test interpretation, this suggests that even though K stratification was statistically significant (Table 2), there would be little or no yield increase associated with further additions of K. Therefore, only a maintenance level, based on estimated crop removal, would be recommended (Voss et al., 1999).

Crop yield at the various soil sampling sites was not measured, so direct comparisons of soil-test change to crop removal were not possible. However, average crop yields for the entire field (Thompson et al., 2000) and estimates of crop nutrient content (Voss et al., 1999) were available, and could be used to calculate P and K removal from the site (Table 4) and a nutrient balance using the P and K inputs (Table 1) and average soil-test changes (Table 3) for the study period. Assuming a bull

Table 4. Field-average crop yields and estimated P and K removal for a 5-year crop rotation on the Thompson Farm near Boone, Iowa.

Year	Crop	Yield (kg ha^{-1})[1]	P removal (kg ha^{-1})[2]	K removal (kg ha^{-1})[2]
1994	Mixed hay	10,306	60	220
1995	Corn	11,259	75	60
1996	Soybean	3,583	48	90
1997	Corn	8,304	62	50
1998	Oat	2,434	30	76

[1] Source: Thompson et al. (2000).
[2] Calculated based on yield using estimated nutrient content of harvested crops (Voss et al., 1999).

density of 1.3 g cm^{-3} for each 5 cm increment throughout the surface 20 cm, changes in soil-test P and K following the 1996 soybean crop accounted for 62 and 107 kg ha^{-1} of the P and K applied prior to moldboard plowing in 1994 (Table 1). A similar calculation following the 1998 oat crop accounted for 60 and 73 kg ha^{-1} of the P and K, respectively, applied through the two manure/sludge applications during the 5-year crop rotation. Adding the soil-test changes to estimates of crop removal for the 1995 and 1996 crops accounts for 88 and 119% of the applied P and K, respectively. Similar calculations following the 1998 oat crop account for 87 and 108% of the applied P and K, respectively. This suggests that the practices currently used for the 5-year rotation will continue to increase soil-test P levels. The calculations also confirm that since Nicollet soils generally have low subsoil K (Voss et al., 1999), additional K applications to meet crop removal will probably be needed to prevent an overall decline in soil-test values.

C and N dynamics

Significant differences in total C and N stratification within the top 20 cm were eliminated by moldboard plowing in autumn 1994 (Table 5), but as with P and K, stratification differences were significant for total N within 2 years and for total C within 3 years after moldboard plowing. Also, even though total C and N stratification were evident, the relatively high organic matter content of this midwestern Mollisol made the difference much less evident than in more highly weathered soils, such as those in the south-eastern US (Hunt et al., 1996). Average values for total C and N were lower in this field than in the nearby field where Cambardella and Karlen (1999) examined spatial variability on this farm. However, in both of the Thompson farm fields, total C and N concentrations were higher than in a nearby 'conventional' field that has been managed in a 2-year corn/soybean rotation since 1957 (Karlen et al., 1995). Presumably this difference in soil organic matter reflects both additional carbon inputs associated with the animal manure/municipal sludge applications and reduced tillage associated with growing oat and forage crops during 2 years of every 5-year rotation.

Ammonium-N and nitrate-N concentrations were also measured each autumn to determine changes throughout the course of a 5-year crop rotation (Table 5). Ammonium levels were lowest following the corn crops (1.6–2.5 mg kg^{-1}) and highest following the hay crop (1994). Concentrations following the soybean crop and establishment of the new seeding ranged from 5.5 to 7.0 mg kg^{-1} NH_4-N. In general, ammonium concentrations were uniform throughout the top 20 cm, showing no significant stratification. Soil nitrate values showed significant differences among depth increments following the hay (1994) and oat (1998) crops (Table 5). The levels found after the hay, first-year corn, and soybean crop were relatively low, and even if all were lost by leaching or tile drainage, the total would only average 18 kg ha^{-1}, and therefore would have minimal environmental impact. However, assuming a bulk density of 1.3 g cm^{-3} for the surface 20 cm, the soil NO_3-N concentrations following the 1997 corn crop, and after the 1998 oat and forage establishment year, were potentially high enough to contribute significantly to leaching loss during the fall, winter and early spring months. Assuming all of NO_3-N present at the time of sampling in those years was lost, the amount would total 70 and 35 kg ha^{-1} for 1997 and 1998, respectively. Preventing such losses of NO_3-N is one reason why a winter rye (*Secale cereale* L.) cover crop is grown on this farm (Thompson et al., 2000). Presumably, growing cover crops and including the mixed hay crop as part of the 5-year rotation are major reasons why studies in an adjacent field with similar long-term soil and crop management (Karlen and Colvin, 1992) showed no significant NO_3-N accumulations in the lower portion of the soil profile.

Soil test methodologies

During the third year of our field study, analytical capabilities for ICP–AES analysis were brought on-line at the NSTL. This enabled us to compare soil-testing methodologies for P and K and to easily obtain additional data for Ca, Mg, Na, Mn and Zn (Table 6) by analyzing just one Mehlich III (Mehlich, 1984) extracting solution (Hanlon and Johnson, 1984). Soil samples from 1994 and 1995 had been discarded, so the methods comparison was possible only for samples collected during 1996, 1997 and 1998. Correlation coefficients (r) comparing Bray extractable P and Mehlich III extractable P (measured by ICP) averaged 0.91, 0.92 and 0.93 for 1996, 1997 and 1998, respectively, when averaged across all four depth increments. These were very similar to the values reported by Mallarino (1997) for soils with pH < 7.4. Coefficients for comparisons between the 1 *M* NH_4OAc exchangeable K and Mehlich III extractable K concentrations were also very high (0.966, 0.986 and 0.996 for 1996, 1997 and 1998, respectively) and statistically significant at $P < 0.0001$.

Because of the high correlation between extracting solutions, we used regression analysis to compute statistical relationships between the two extraction methods (Equations 1 and 2).

$$\text{Mehlich III Extractable P} = 23.6 + 1.3(\text{Bray extractable P}) \quad (1)$$

$$\text{Mehlich III Extractable K} = 4.9 + 0.94(1\,M\ NH_4OAc \text{ exchangeable K}) \quad (2)$$

Table 5. Yearly fluctuation in total N, total C, ammonium- and nitrate-N for a Nicollet loam managed in a 5–year crop rotation on the Thompson Farm near Boone, Iowa.

	Year/crop				
	1994/hay	1995/corn	1996/soybean	1997/corn	1998/oa
Soil depth (cm)			Total N ($mg\,kg^{-1}$)		
0–5	2912	2481	2217	2942	2667
5–10	2541	2475	2250	2783	2333
10–15	2172	2176	2150	2542	2175
15–20	1837	2270	1925	2533	2067
LSD (0.05)	130	NS	219	170	171
			Total C ($g\,kg^{-1}$)		
0–5	34.7	31.6	30.0	36.4	33.4
5–10	30.3	31.8	29.7	34.2	29.6
10–15	26.6	28.3	29.0	31.7	28.3
15–20	24.2	28.2	26.6	32.1	27.3
LSD (0.05)	1.8	NS	NS	2.0	2.5
			NO_3-N ($mg\,kg^{-1}$)		
0–5	7.0	6.2	7.9	30.3	18.9
5–10	6.8	7.2	8.4	28.0	15.2
10–15	5.4	7.7	7.8	25.9	10.2
15–20	5.6	7.1	7.6	24.0	9.5
LSD (0.05)	0.9	NS	NS	NS	6.5
			NH_4-N ($mg\,kg^{-1}$)		
0–5	9.4	1.6	5.5	1.8	6.0
5–10	9.1	2.2	6.0	2.5	7.0
10–15	9.4	1.8	5.7	2.2	5.7
15–20	9.3	2.0	5.9	1.7	5.5
LSD (0.05)	NS	NS	NS	NS	1.0

The relationships are statistically highly significant ($P < 0.0001$) as observed for individual sampling depths (Tables 2 and 6) or for the surface 20 cm averages (Table 3). Therefore, when averaged for the 0–15 cm depth to use ISU soil-test guidelines (Voss et al., 1999), our study confirms that both extracting solutions would result in similar soil-test ratings. These findings also support the conclusions of Hanlon and Johnson (1984) and confirm that farmers and other land managers can use P and K soil-test results based on either extraction method. However, our data were limited to a single soil with 'high' or 'very high' P and K concentrations. Therefore, the statistical relationships shown in Equations 1 and 2 would not be valid for soils with low P or K concentrations. This is very evident for P (Eqn 1) where a 'very low' Bray test (0–8 $mg\,kg^{-1}$) would result in a 'very high' Mehlich III rating. This emphasizes the need for full-scale calibration (very low to very high soil-test levels) before developing statistical relationships to convert soil-test values from one extractant to another. Our experience with the ICP–AES methodology for P was also promising, and although not currently recommended by the North Central Regional Committee on Soil Testing and Plant Analysis (Voss et al., 1999), the results indicate that use of ICP–AES and multi-element analysis warrants further evaluation for soils throughou this region.

A major reason for switching from the traditional Bray P an ammonium acetate soil-test methods is that Mehlich III is multi-element extracting solution. Thus, coupled with ICP–AE instrumentation, adoption of this methodology can provid substantially more information with very little additional cos This benefit is evident in Table 6, which in addition to P and K also includes mean values for extractable Ca, Mg, Na, Mn an Zn. Our interpretation of those data does not suggest any trend or patterns that should be of concern or have an impact on th crops being grown at this site. For example, despite frequen applications of animal manure/municipal sludge, Na concentra tions are very low throughout the surface 20 cm. Similarly, eve though the average soil-test P level for the upper 15 cm is 'high or 'very high', the extractable Zn concentrations (Table 6 indicate that the probability of a P-induced Zn deficiency is ver low. In fact, Zn concentrations are nearly 10 times greater tha the concentrations at which Zn would be recommended for cor or sorghum [*Sorghum bicolor* (L.) Moench] production (Vos et al., 1999). Presumably this reflects the fact that Zn is bein added at rates ranging from 0.7 to 3.2 $kg\,ha^{-1}$ whenever th

animal manure and municipal sludge mixture is applied (Thompson et al., 2000).

Table 6. Yearly fluctuation in Mehlich III extractable P, K, Ca, Mg, Na, Mn and Zn for a Nicollet loam managed in a 5-year crop rotation on the Thompson Farm near Boone, Iowa.

	Year/crop		
	1996/soybean	1997/corn	1998/oat
Soil depth (cm)	Mehlich III extractable P (mg kg^{-1})		
0–5	136	209	225
5–10	128	148	158
10–15	113	113	115
15–20	97	99	96
LSD (0.05)	17	32	31
	Mehlich III extractable K (mg kg^{-1})		
0–5	224	320	324
5–10	158	192	156
10–15	155	158	125
15–20	152	150	112
LSD (0.05)	31	64	65
	Mehlich III extractable Ca (mg kg^{-1})		
0–5	4468	4881	5390
5–10	4518	4668	5144
10–15	4448	4392	4803
15–20	4405	4620	4891
LSD (0.05)	NS	NS	318
	Mehlich III extractable Mg (mg kg^{-1})		
0–5	416	396	424
5–10	417	370	418
10–15	427	361	412
15–20	432	383	434
LSD (0.05)	12	NS	NS
	Mehlich III extractable Na (mg kg^{-1})		
0–5	14	28	46
5–10	16	29	46
10–15	20	28	40
15–20	23	28	40
LSD (0.05)	3	NS	NS
	Mehlich III extractable Mn (mg kg^{-1})		
0–5	96	75	83
5–10	88	74	78
10–15	83	72	73
15–20	75	70	73
LSD (0.05)	7	NS	NS
	Mehlich III extractable Zn (mg kg^{-1})		
0–5	11.0	12.2	17.4
5–10	10.6	9.5	13.0
10–15	9.6	7.2	10.5
15–20	7.6	6.2	8.8
LSD (0.05)	1.5	2.4	2.2

Soil-test interpretation philosophies

Implementing the Mehlich III methodology for multi-element soil-test analysis also enabled us to examine the data using both the 'sufficiency level' and 'basic cation saturation ratio' philosophies for soil-test interpretation. This was done because questions regarding cation ratios continue to be asked by farmers and some crop consultants, even though Rehm (1994) and Olson et al. (1985) concluded that: (1) cation ratios have no impact on the response of crops to Ca, Mg and K in fertilizer programs; and (2) there can be a wide range in the cation ratios without any effects on crop yield or quality.

Cation saturation percentages (Table 7) were calculated and summed for the surface 20 cm using measured concentrations for 1996 through 1998 at each sampling depth (Table 6). We ignored any contribution for exchangeable acidity (H^+), but since soil pH was approximately 7 at each depth (Table 2), this was assumed to be acceptable. We also recognized that BCSR values are normally computed using estimated or measured cation exchange capacity (CEC), so for comparison with the summation approach, CEC was measured for a subset of the soil samples using displacement and washing with $BaCl_2$ (Hendershot and Duquette, 1986). The measured CEC values (Table 7) and the sum of Mehlich III extractable bases showed similar patterns at each depth increment, but the summation procedure consistently gave slightly higher values. This was presumably due to the extraction of some non-exchangeable cations by the Mehlich III extractant, a relationship that was also indicated by the regression equation comparing Mehlich III extractable K and ammonium acetate exchangeable K (Eqn 2). Since the Mehlich III solution also extracted more P (Eqn 1), we assumed that Ca, Mg and Na levels may also be slightly higher than if they were measured using 1 *M* NH_4OAc.

For relative BCSR comparisons, we hypothesized that the percentages would be similar for either soil-test extracting solution. This hypothesis was tested using unpublished soil-test data from 13 different sites across Iowa. For those samples, both Mehlich III and 1 *M* NH_4OAc extractants had been used and direct comparisons of K, Ca and Mg concentrations were possible. Saturation percentages were computed using the sum of Mehlich III extractable bases, plus estimated exchangeable acidity versus the sum of 1 *M* NH_4OAc exchangeable bases plus estimated exchangeable acidity. Our results showed significantly higher Ca extraction by the Mehlich III solution (13.8 versus 9.9 cmol kg^{-1}) but no significant differences in the amount of K or Mg. Therefore, when expressed on a percentage basis, the differences in Ca extraction caused the K saturation percentages to be significantly lower (2.4 versus 3.0 cmol kg^{-1}).

We had anticipated relatively low K percentages because, during the mid–1980s, our cooperator had encountered severe K deficiencies in his corn crops (Thompson et al., 2000). This was attributed to two farm management practices occurring during that time period. The first was a high K leaching loss associated with in-field composting of cattle (*Bos taurus*) and hog (*Sus scrofa*) manure from 1975 through 1983. Composting was used to reduce weed seed populations, but the nutrient loss associated with the process resulted in very low K applications to many of

Table 7. Measured cation exchange capacity (CEC) and calculated cation saturation percentages for a Nicollet loam managed in a 5-yea crop rotation on the Thompson Farm near Boone, Iowa.

Soil depth (cm)	CEC (cmol kg^{-1})[1]	Total bases (cmol kg^{-1})[2]	Calculated base saturation (%)			
			Ca	Mg	K	Na
0–5	25.2	28.8	85.5	12.1	2.66	0.4
5–10	24.1	27.7	84.8	12.3	1.62	0.4
10–15	23.6	26.5	85.2	12.8	1.48	0.5
15–20	20.9	27.0	85.0	13.2	1.37	0.5
LSD (0.05)	3.3	1.0	0.3	0.4	0.26	0.0

[1] Measured using displacement with $BaCl_2$.
[2] Summation of Mehlich III extractable bases (K, Ca, Mg and Na); H^+ was not included because average soil pH for each depth ranged from 6.9 to 7.1 (Table 2).

our cooperator's fields throughout that time period. A second factor presumably contributing to the low K saturation was that, prior to 1997, either dehydrated lime or cement kiln dust was added to municipal waste water to raise the biosolids pH and thus reduce pathogen populations. Adding lime or kiln dust undoubtedly increased the amounts of Ca and Mg relative to K. Subsequently, when the mixture of animal manure and municipal sludge was taken from the storage bunker and applied to the fields as the primary nutrient management program (Thompson et al., 2000), the imbalance among K, Ca and Mg in the soil was presumably accentuated. This use of the cation ratio approach for interpreting the soil-test data from our 5-year crop rotation study, coupled with the additional measurement of CEC and comparisons of soil-test methods on samples from 13 other sites, thus provided one explanation for the low K saturation percentages (Table 7).

An analysis of variance of the average 0–20 cm soil-test data summarized in Table 7 showed no significant differences among years for calculated total bases, percent K or percent Ca saturation. There were statistically significant differences among years for percent Mg (13.6, 11.8 and 12.4 for 1996, 1997 and 1998, respectively; $LSD_{0.05} = 1.2$) and percent Na (0.30, 0.48, and 0.67, respectively; $LSD_{0.05} = 0.11$). However, based on the broad ranges in cation saturation that are reported in the literature (Eckert, 1987; Kelling et al., 1996; Rehm, 1994), we conclude that those yearly differences had very little agronomic significance. An interesting point to us in this evaluation was that for all four depth increments Ca saturation is at the maximum level and Mg saturation is at or above the desired saturation percentages proposed by Graham (1959) for Missouri soils. Undoubtedly, all of the soil-forming factors (parent material, climate, vegetation, time and topography) have an effect on the anticipated BCSR values, but, except for the surface 5 cm, the K saturation percentages (Table 7) were generally below Graham's (1959) 2–5% level.

We recognize that our use of the Mehlich III extractant probably aggravated the BSCR comparisons by increasing the relative amount of Ca that was extracted. However, if regression relationships developed for K, Ca and Mg extracted by Mehlich III and 1 *M* NH_4OAc in soil samples from 13 other sites across Iowa (not presented) are used to estimate 1 *M* NH_4OA exchangeable values for this field site, saturation percentage throughout the top 20 cm of the soil profile average 3, 78 an 19% K, Ca and Mg, respectively. These calculated values als suggest that K saturation was low and that Mg saturation wa well above the 'desired' level (Graham, 1959).

A final comparison that provides another indication of hov our cooperator's long-term soil management practices ar affecting his soils was made by comparing our measured an calculated data with that from a non-cultivated fence corne (Thompson et al., 2000). We recognize that wind erosion ma have affected the fence row site, but since it was never tilled i can provide an indication of how farming has affected soils i this area. The samples from the fence corner had a CEC o 19.9 cmol kg^{-1}, 70 g kg^{-1} organic matter, pH of 6.8, and K, C and Mg saturations of 5, 70 and 25%, respectively in the to 15 cm. Meanwhile, the average values for our field site showed CEC of 24 cmol kg^{-1}, 31 g kg^{-1} organic matter, pH of 6.8, and K Ca and Mg saturations of 3, 78 and 19%, respectively. Thi comparison shows a loss of organic matter that is quite typica for this area, and suggests that K and Mg saturation percentage have declined, while Ca saturation percentages have increased

One possible effect of the low K saturation percentages is tha they help explain why on-farm fertilizer response trial evaluating effects of applying supplemental K fertilizer hav shown improved corn yield and profitability in four out of fiv trials (Thompson et al., 2000). This response was observed eve though sufficiency-level soil-test interpretations suggest that deficiency problems would not be anticipated. Our suggestion o reduced K availability based on BCSR interpretation of soil-tes data is not intended to contradict any of the other reasons (e.g increased compaction, changes in root density and elongatio rates, lower soil temperatures, slower diffusion because o increased soil bulk density, or differences in root architectur among hybrids) given to explain K deficiencies in ridge-till cor in the northern Corn Belt (Allan et al., 1992; Rehm and Fixe 1990). Rather, it is offered as another factor contributing to the problems encountered by our cooperator and to suggest tha additional field studies evaluating where and how the BCSR soi test interpretation philosophy may be useful are warranted.

Summary and Conclusion

This study of soil-test dynamics on the Thompson Farm, near Boone, Iowa, has shown that although moldboard plowing can eliminate or reduce P and K stratification, incremental soil sampling can show significant differences again as soon as 2 years later. However, based on sufficiency-level soil-test interpretations, current animal manure/municipal sludge applications in 2 of every 5 years of the rotation have maintained soil P and K concentrations at levels where no crop response to additional fertilizer would be expected.

Comparisons of soil-test methodologies for this relatively 'high' fertility soil indicate that using the Mehlich III multi-element extractant and inductively coupled plasma–atomic emission spectrometer (ICP–AES) analysis provided concentration data that, when averaged for the 15 cm depth, resulted in the same Iowa State University soil-test P and K rating (i.e., medium, high or very high) as the Bray P1 and 1 *M* NH_4OAc extracting solutions. The advantage for using the multi-element methodology is that it can provide farmers and other decision makers with additional soil-test information at very little additional cost. An apparent disadvantage for using the Mehlich III extractant for Nicollet loam and other Iowa soils is that it extracts more Ca than does 1 *M* NH_4OAc. This may be a problem if the cation concentration data are to be evaluated using a cation ratio soil-test interpretation philosophy.

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The wholesale produce auction: An alternative marketing strategy for small farms

Stephan Tubene and James Hanson

Abstract. *Small farmers urgently need alternative marketing strategies if they are to achieve the goals of a more sustainable agriculture. This study was a survey of nine Pennsylvania wholesale produce auctions, all established between 1984 and 1998. The main goals of the auctions were to serve local communities, provide high-quality produce to local consumers and make profits. The results showed that the auctions typically employ an average of 7–10 people per growing season. The five most common commodities sold were cantaloupe, watermelon, tomato, pumpkin and sweet corn. Asparagus and onions were the least sold during a regular growing season. In terms of market share, roadside market operators purchased the largest proportion of produce (40%), followed by farmers (27%), chain food stores (16%), independent grocery stores (11%) and restaurants (6%), making up an average annual gross sale of $3.5 million per auction. The study revealed that the nine Pennsylvania produce auctions were successful in meeting their goals. The reasons for success included private ownership, excellent quality and freshness of produce, good location, local produce recognition, clientele availability and customer-oriented business. The auction managers identified some weaknesses, including inconsistent and poor grading, limited space in the auction facility, produce unavailability and limited volume, lack of cooling facility, price fluctuation and slow service. The study indicated that local wholesale produce auctions are a useful marketing alternative for small farmers in Pennsylvania, by providing marketing outlets and convenient shopping centers for sellers and buyers; by securing a source of fresh and locally grown produce not found in traditional wholesale terminal markets; and by allowing exchange and networking among farmers and buyers. Consequently, the wholesale produce auction can be a useful model for an alternative marketing strategy and can provide considerable benefits to small farm and rural communities.*

Key words: alternative agriculture, market share, produce marketing, risk management, roadside market operators, rural America, sustainable agriculture

Introduction

In recent years, small farms have struggled to keep up with economic and technological changes that have affected the US agricultural industry. The competitive world in which small farms operate, coupled with the development of giant firms, have created a risky and uncertain business environment for small farms. Should small farms market their produce through the traditional chain food stores and terminal markets, or are there other marketing strategies that small farms may adopt? According to Sustainable Agriculture Network (SAN, 1999b), farmers in very rural areas need to be more creative than their large farm counterparts located near population centers where there are more opportunities to interact with consumers. Small farmers' creativity may include options such as diversification, value-added products, cooperatives, wholesale produce auctions, mail order and Internet marketing. Alternative marketing strategies, as well as risk management tools, may be the key to the survival of small farms in the more remote areas.

Diversification is not only a risk management tool but also a technique that can protect the natural resources and spur community economic development. By diversifying their enterprises and marketing strategies, farmers could minimize the risk of losing all of their business if one enterprise fails. As recently reported by SAN (1999a), adding new crops into a rotation helps producers not only to make money but also to increase yields of the traditional crops in the rotation. In addition, marketing alternative crops directly often creates local opportunities to process, package and/or sell new products, spurring economic development within the community.

Significant changes in the US agricultural markets over the past decade have literally revolutionized the US food industry as a whole. Many interrelated factors have driven these changes, including technological innovation, increasing ethnic diversity, health consciousness, expanded advertising programs, prices, consumer income, new products and convenience (Schluter et al., 1998). According to Kohls and Uhl (1992), consumer tastes and preferences drive the nation's food and fiber system. For example, by meeting immigrant consumer preferences for ethnic produce, producers expand their market niches to new audiences and create new sources of income. Hence, the ultimate task of the food marketing system is to deliver the food consumers need. Barkema (1993) argued that a key job of the food market is to ensure that food products are accurately targeted at market niches, regardless of their size.

Developing a wholesale marketing strategy as an alternative marketing tool for produce can be time consuming, especially

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when it involves auction markets. Yet, this strategy may be a viable alternative for small farmers in rural communities to market their produce, since it provides both produce quantity and networking opportunities to the market participants.

According to Hanson and Rada (1992), farmers must seek out their own wholesale customers and deliver quality produce in order to succeed in the Mid-Atlantic wholesale produce markets. Forming agricultural cooperatives may also allow small farmers to pool resources to better serve wholesale customers.

A study by Blaine et al. (1996) on the effects of a wholesale fruit and vegetable auction on produce marketing and distribution indicated that an auction in north-east Ohio was an efficient and accepted part of the local food-marketing system. The auction improved the efficiency of the marketing system and also helped involved individuals and families reach their economic and social goals. In addition, the study concluded that wholesale fruit and vegetable auctions appeared to have considerable potential as economic development tools for communities with large Amish populations.

The objectives of this study were to (1) examine how Pennsylvania wholesale produce auctions operate, (2) evaluate strengths and weaknesses of their operations, and (3) determine whether a wholesale produce auction as an alternative marketing strategy is a viable marketing model for other small farm communities. The research was based on a survey of 9 (out of 10) Pennsylvania produce auctions (Tubene et al., 1999).

Data and Methods

A personal survey for use with auction managers was developed to answer the objectives of this study. The original questionnaire was reviewed and field-tested with a Maryland auction manager before using it to interview Pennsylvania produce-auction managers. The questionnaire contained five major components including auction personal data (name and address, person and date interviewed), general questions (business establishment, ownership and advertisement), market facility (size of the facility, equipment, record-keeping and number of employees), market operations (produce volume, numbers of sellers and buyers, market location and schedule, population served and educational programs) and business organizational matter (financial information, market strengths and weaknesses). The questionnaire was developed as single-time surveys (Duncan and Kalton, 1987) with both closed and open questions.

A list of auction managers was obtained from the owner of a wholesale produce auction in Pennsylvania. There are currently 10 wholesale produce auctions scattered throughout Pennsylvania. Nine produce-auction managers were personally interviewed in the spring and the summer of 1999 at their respective auction sites. One manager declined to be interviewed. Data were collected following a face-to-face interview method (Barnett, 1991). These data, collected from the nine produce auctions, represents a 90% response. All data were collected from auction managers, except for some financial details. Three auction managers did not disclose financial records of their operations for security and privacy reasons. Financial data were provided by six auction managers. Data were finally compiled and analyzed using WINSTAR (1994), an econometrics computer program. A descriptive statistics model was used to estimate the auction variables.

Results and Discussion

Market facility

Pennsylvania produce auctions are corporate and family-owned business wholesale markets, and the major goal of these is to serve local communities by providing a facility and a mechanism that brings producers and buyers together. Other goals are to offer high-quality produce to the market participants and to make profits (Table 1).

According to the survey, the typical size of the Pennsylvania auctions' building is about 21 m (70 feet) wide and 70 m (228 feet) long, representing a minimal investment of $1.5 million (Table 2).

Equipment used by most of the Pennsylvania auctions includes fork lift, hand pallet jack, electric jack, carts, boxes and office items. Other equipment, such as a produce cooling system, freezer and computers, are not common (only two used a cooling facility and one a freezer to store fresh produce). The cooling system was used to store more fresh produce and secure a higher demand for the produce. The freezer provided ice to the growers for their post-harvest needs at the produce auction.

All nine auctions maintained records of transactions that were primarily finance and sale records. Five managers said they maintained hand-written or manual reports. Five out of the nine auctions did not use computers for their daily operations, simply because they had not yet acquired this technology. The

Table 1. General description of nine Pennsylvania produce auctions.

Questions	Responses
Business ownership?	Private, corporation and family business
Major goal of the market?	Serve local communities; offer quality produce; make a profit for sellers
Market type?	Wholesale auction markets
External financial support?	None
Community involvement?	Local community support through farmers and buyers who do business with produce auctions
Means of advertisement?	Local newspapers, personal contact, direct mail, reputation, word of mouth, newsletters, meetings, long-term establishment

Table 2. Characteristics of nine Pennsylvania produce auction facilities.

Characteristics	Responses
Size of auction's building	Average size: 21 m × 70 m (70 ft × 228 ft) Largest size: 21 m × 107 m (70 ft × 350 ft) Smallest size: 18 m × 46 m (60 ft × 150 ft)
Equipment	Cooling system, freezer, forklift, carts, hand pallet jacks, electric jacks, boxes, office equipment
Transaction records	Finance records, sales records, manually written records
Use of computers	Very limited: mainly used for record keeping and auction transactions
Number of employees	7–10 (depending on the growing season)
Positions	Manager, assistant manager, auctioneer, treasurer, secretary, clerk, warehouse workers
Use of educational materials	Through Pennsylvania State University Cooperative Extension Service

remaining four used their own business computer software for record-keeping and auction transactions.

The produce auctions employed an average of 7–10 employees. These included an auction manager, an assistant manager, an auctioneer, a treasurer, a secretary, clerks and warehouse workers. The actual number varied with the season. A limited number of workers are needed at the beginning of the season, but as the peak is approached, more are hired to handle the growing volume of produce. While the manager position is often full-time, other duties may be accomplished on a part-time basis.

Auction managers were asked if they generated any newsletters and/or educational materials for the market participants, or the public at large. In general, they did not on a regular basis. Most published an auction guide each year at the beginning of the season to advertise their produce. The survey showed that 67% of produce auctions published a market report in local newspapers to advertise their businesses to the local community. For advertising, all of the auctions relied on word of mouth, direct contacts, reputation and their long-term establishment (Table 1). None of the auctions published educational materials. Nevertheless, educational materials, such as production pointers, pest management, horticultural and marketing fact sheets, were distributed to the market participants by the Pennsylvania State University Cooperative Extension Service.

Market operations

Prior to the produce harvest season (i.e., November–April), other products are sold, including flowers and bedding plants. The auction managers indicated that the average largest volume of produce items sold at Pennsylvania auction markets were cantaloupe (*Cucumis melo*), watermelon (*Citrullus lanatus*), tomato (*Lycopersicon esculentum*), pumpkin (*Cucurbita pepo*), and sweet corn (*Zea mays* L.). Asparagus (*Asparagus officinalis*) and onions (*Allium cepa*) were the lowest volume items.

When asked about the number of sellers and buyers with whom they conduct business at a facility, the auction managers stated that, on average, approximately 300 growers market their produce, and 200 buyers purchase produce at each auction (Table 3). Among the 300 sellers and 200 buyers of produce, only 50 sellers (17%) and 90 buyers (45%) were regular attendees of an individual produce auction. The study indicated that roadside market operators purchased the highest proportion of the commodities (40%), followed by farmers (27%), chain food stores (16%), other grocery stores (11%) and restaurants (6%). In the case of farmers, some purchased produce for resale.

Most Pennsylvania produce auctions do not have special delivery arrangements with any businesses. Buyers and sellers meet at the auction, where produce items are exchanged after the auctioneer establishes the price through the bidding process. Only one produce auction had special delivery arrangements with local chain food stores.

Cooling systems were uncommon in the Pennsylvania produce auctions. Only two of the nine had cooling facilities. When questioned why there were not more, the managers replied that there was no need for these because of the quick turnover of the local fresh produce. Two managers indicated that such a facility could increase the availability of the produce over a longer time, as well as the volume. Thus, in some cases, a cooling facility would appear to be advantageous.

None of the nine produce auctions signed any contractual arrangements with businesses (i.e., restaurants, and chain food stores) for lack of any financial incentives. Commitment to specific businesses would limit their customer base and opportunities for better prices. According to the auction managers, a flexible marketing strategy, giving access to a variety of buyers, brings better prices and allows for more flexible decisions.

Prices of produce are usually determined through the bid process. The produce is always sold to the highest bidder. The auction managers reported that prices of produce are higher early and late in the harvest season when the supply is low. This information should encourage farmers to adjust their planting dates for harvesting produce at these times. Early, as well as late crops in the season will bring higher returns to farmers, if yield is not reduced.

All nine produce-auction managers reported that the access to their markets was equally fair to all market participants. When asked whether their facilities serve local, regional or national clientele, all managers replied that the produce was grown locally and sold regionally. Surprisingly, occasional lots of produce obtained from as far as Florida, Georgia and the Carolinas are sold at Pennsylvania produce auctions.

Table 3. Summary of market operations for nine Pennsylvania produce auctions.

Market operations	Responses
Number of sellers	Average of 300 (50 are regular sellers)
Number of buyers	Average of 200 (90 are regular buyers)
Purchasers at auctions	Chain food stores (16%), independent grocery store (11%), farmers (27%), restaurants (6%) and roadside market operators (40%)
Special delivery	Delivery made only by one of the nine wholesale produce auctions
Cooling facility	Three wholesale produce auctions have cooling facilities
Contractual arrangements	None
Price determination	Highest bidder and by law of supply and demand
Access to the market	Open to all market participants
Market location and service	Located in close proximity to producing area and convenient rural low-speed roads
Weekly schedule	2–day average weekly schedule with a 4–day peak season schedule
Buyers' and sellers' interaction	Networking: exchange of market tips and recipes
Community diversity	Multicultural community but not yet being served with ethnic produce

Table 4. Strengths of nine Pennsylvania produce auctions.

Factors	Responses
Business ownership	Corporation (6) Family-owned business (3)
Board of Directors	Responsible and qualified Board members
Current commission rate	Variable (8–10%)
Produce quality	Excellent quality, diverse, local and fresh
Auction location	Rural farming communities Not near traditional marketing outlets
Clientele	Available customers (i.e., buyers and sellers)
Management	Customer-oriented, honest and friendly

All of the Pennsylvania auctions were located in proximity with rural production areas. This helps to reduce farmers' transportation costs. The survey showed that all auction facilities avoided locating along a high-speed roadway that could make access to the market very inconvenient to market participants. This has been a handicap for farmers in other states where the lack of traffic lights required that farmers yield to oncoming vehicles. All were located in rural areas with predominantly Amish communities.

All of the auctions operated throughout the season, 1–6 days a week, depending on the supply of produce. The typical schedule was 2 days a week, usually on Tuesdays and Thursdays. Business during the harvest seasons usually begins slowly and increases as produce becomes more available during peak times. The markets are typically open 1 day a week during the winter, twice weekly in spring and fall; and sometimes 4 days a week in the summer (July–September), during the peak harvest season.

Do Pennsylvania produce auctions actively seek out customers through advertisement and other means of communication? The answer is 'yes'. They actively seek out producers and buyers through advertisements in local newspapers, personal contact, direct mail, word of mouth, long-term establishment, reputation, meetings and newsletters. Another aspect of produce auctions is networking. The survey indicated that sellers and buyers were able to interact and share market tips and recipes at the auction.

The population served by these auction markets is diverse (i.e., Amish, white and some minority groups). Over half of the managers thought that the community being served by their markets is multicultural. However, there were not yet ethnic vegetables and herbs offered at these auctions, suggesting that there could be a niche market for ethnic produce, given the diversity of the population served.

None of the produce auctions provided educational programs. However, auction managers indicated that the Pennsylvania Cooperative Extension agents/educators provided educational programs such as production, farm management and horticultural sessions at the auction facilities. In addition, two auctions organized growers' meetings, intended to evaluate the performance of previous auctions and to provide directions for the next season.

Market strengths and weaknesses

Six of the nine markets were corporate auctions governed by a board of directors, whereas three were family-owned auctions that did not have a board of directors. The auctions reported that they were able to cover all expenses and make a profit at the fourth year (on average) of their operation. In some cases, profits were made at their second year. Several auctions were forced to replace their original board of directors with new members to improve efficiency and productivity.

Three produce auctions did not provide financial data for security and privacy reasons. Based on the six that did, in 1998, the average annual gross sales were estimated at $3.5 million with a total commission of $290,500. Seven of the produce auctions charged an 8% commission rate. One auction charged a 9% commission rate and another a 10% rate, due to their geographical location. These rates did not significantly affect sales of these markets because they were far enough away to avoid competition from other produce auctions.

The auctions' strengths include excellent quality of produce, optimum locations, local produce recognition, clientele availability, management skill, hard work, customer-oriented business and private business ownership (Table 4). Most of the surveyed managers said that poor grading was the major factor

Table 5. Factors limiting the growth of Pennsylvania produce auctions.

Factor	Responses
Major	Poor grading
Other	Limited space in the auction facility
	Produce unavailability
	Produce limited volume
	Lack of cooling facility
	Price fluctuation
	Slow service
	Competition (i.e., farmers' direct sales)
	Drought
	Labor shortage
	Business ownership

limiting business growth (Table 5). However, grading deficiency could be corrected through education and rewarded by higher prices to sellers. Other factors that might hinder business growth included limited space in the auction facility, unavailability of produce, limited volume of produce, lack of cooling facility, price fluctuation and slow service. One manager indicated that other factors such as competition (farmer direct sales), drought, labor shortage, and type of business ownership could also limit the growth of produce auctions (Table 5).

Farmers could take advantage of price fluctuations to adjust their planting dates for harvesting during more profitable market windows (i.e., early and late in the season). Similarly, accessing a cooling facility and more auction space to serve more vendors could help negate a produce shortage. More space and a cooling facility could help ensure the availability of commodities and meet a higher demand for the produce.

A produce auction can be slow and time consuming. However, small farmers in rural areas often do not have ready access to alternative markets (i.e., chain food stores, terminal markets) and, therefore, the best option for them may be to sell produce through a local auction. Contract arrangements, purchasing cooperatives and other direct marketing opportunities could be created locally to help farmers shift market risks away from them and ensure produce availability.

Inconsistent or poor grading of produce at the auctions can be improved through educational programs conducted in cooperation with the Pennsylvania State University Cooperative Extension Service. The survey revealed that all of the produce auctions met their market expectations and goals as initially planned. However, none of them made a profit the first year of operation.

Conclusions and Recommendations

Our survey revealed that 10 wholesale produce auctions were established in Pennsylvania between 1984 and 1998. Their goal was to serve their local communities by providing high-quality produce to local consumers and marketing opportunities for local farmers.

The average size of the auction building is about 21 m (70 ft) wide and 70 m (228 ft) long. Only three of the auctions utilized cooling facilities and four used computers for their daily business operations.

The auctions typically employed an average of 7–10 people per growing season. The most common produce sold included cantaloupe, watermelon, tomato, pumpkin and sweet corn. Asparagus and onions were the least sold commodities during a regular growing season.

The produce auctions' largest market share was roadside market operators (40%), followed by farmers (27%), chain food stores (16%), independent grocery stores (11%) and restaurants (6%), making up an average annual gross sale of $3.5 million. The auctions' strengths included private business ownership, fresh produce of excellent quality, good locations, local produce recognition, clientele availability and customer-oriented business. Weaknesses included inconsistent or poor grading of produce, limited space in the auction facility, produce unavailability and limited volume, lack of cooling facilities, price fluctuation and slow service.

It was concluded that these wholesale produce auctions could provide an alternative marketing strategy for small farms in the rural areas. The Pennsylvania auction model indicates that this marketing scheme is appropriate in rural areas where traditional alternatives, such as terminal markets and chain food stores, are not available. This alternative market offers a promising option for small farms to sell produce, and a convenient shopping center for buyers. While some weaknesses exist in these auction-type markets (which can be corrected), their strengths and successes suggest that such wholesale marketing can help sustain small farms. The policy implication of this study is that a wholesale produce-auction market model is highly recommended for rural communities.

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Climate Change and Global Crop Productivity

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Barriers to the adoption of organic farming by cash-crop producers in Austria

Walter Schneeberger, Ika Darnhofer, and Michael Eder

Abstract. *Most of Austria's organic farms are located in mountainous areas and produce mainly milk and beef, whereas a low percentage of cash-crop farms are organic. As a result, the demand for organically grown crops cannot be fully met by domestic production. This paper investigates the barriers to adoption of organic agriculture by cash-crop farmers in Austria. In a written survey, 383 conventional farmers provided information on their perception of organic farming and rated the importance of potential barriers to adoption. Technical challenges in cropping and additional labor requirements were rated as the most important barriers, followed by fear of decreased income and marketing problems. Structural and social issues, such as farm size and lack of support from family members, were less important.*

Key words: barriers to conversion, conventional farming, European Union, organic agriculture, organic cereals, organic management, organic vineyards, regulations

Introduction

There has been a rapid increase in the number of organic farms in Austria since the early 1990s (Vogl and Hess, 1999). In 1999, 9.8% of the 201,500 Austrian farms were under organic management (BMLFUW, 2000; Statistik Austria, 2001). This is largely due to an effort by the Austrian government to encourage both the conversion to, and the maintenance of, organic farming through the Austrian Agri-environment Program 'ÖPUL' (the full title of the ÖPUL in German is: Österreichisches Programm zur Förderung einer umweltgerechten, extensiven und den natürlichen Lebensraum schützenden Landwirtschaft, which can be translated as: Austrian program to promote an environmentally conscious, extensive and natural habitat protecting agriculture). Organic agriculture is one of the 31 defined practices or 'measures' included in the program, and farmers implementing one or several of the practices on a voluntary and contractual basis receive compensatory payments.

The organic farms are concentrated in the mountainous areas of western Austria and are predominantly dairy farms with permanent grassland (Kirner and Schneeberger, 1999). In the eastern and northern parts of Austria, where land use is dominated by arable farming, conversion to organic production methods has proceeded at a slow rate. As a result, domestic production of organic milk and organic beef exceeds the demand, whereas the domestic production of organic grain is well below demand (Michelsen et al., 1999). This shortage persists despite calculations which indicate that conversion to organic farming could be economically advantageous for cash-crop farmers (Eder, 1999). Thus, it is likely that other barriers are limiting the adoption of organic practices.

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Several studies have analyzed the barriers to the conversion of conventional farmers to organic methods and practices (Freyer et al., 1994; Hollenberg et al., 1999; Kirner and Schneeberger, 2000; Köhne and Köhn, 1998; Lockeretz, 1999; Loibl, 1999; Noe, 1999; Padel and Lampkin, 1994; Schneider, 2001). However, few studies (e.g., Kirner and Schneeberger, 2000) have specifically addressed the barriers to conversion as perceived by cash-crop farmers.

The overall objectives of this study were to (1) identify barriers to adoption of organic farming by conventional arable cash-crop farms in Austria, and (2) derive efficient strategies for increasing the number of organic cash-crop producers. The specific objectives of the study were to:

- describe differences in farm size and cropping patterns of conventional and organic farms in the study area;
- assess the attitudes and perceptions of conventional farmers towards organic farming;
- investigate the importance of various potential barriers to adoption of organic farming methods by conventional farmers;
- investigate various variables that could influence farmers' perceptions of barriers to adoption; and
- compare the findings of this survey with other studies focusing on barriers to the adoption of organic farming by conventional farmers.

Database and Methods

Study area

The Weinviertel, as defined by the nomenclature of territorial units for statistics (NUTS III) of the European Office for Statistics, was selected as the study area. This region in northeast Austria was chosen as it has a low percentage of organic farms (1%), cash-crop farming is dominant, and it is close to Vienna with its large demand for organic products. Also, its dry

climate and limited irrigation possibilities makes input-intensive agriculture less profitable. Although vineyards are present, agricultural practices on arable land can be described as characteristic for cash-crop farming in north-east Austria.

Database

The differences in cropping patterns between conventional and organic farms in the study area were analyzed using the 1999 federal database INVEKOS (Integrated Administration and Control System). It covers all farms receiving direct payments within the framework of the Common Agricultural Policy of the European Union (EU) and those that participate in the Austrian Agri-environment Program. The database included 6515 conventional and 71 organic farms in the study area.

Information on the perception of organic farming by conventional farmers was collected through a written survey using a four-page questionnaire. The questionnaire was mailed to 1000 randomly selected farms in September 2000, followed by a reminder card 6 weeks later. By the end of November 2000, 424 questionnaires had been returned. Of these, 41 were blank, mainly because farming had been abandoned.

Data analysis

Some of the 383 completed questionnaires did not have an answer for each item. The likely reasons are that not all items applied to every farm (e.g., questions regarding viticulture for farms without vineyards), and that some farmers did not have definite opinions on some questions. It was assumed that there was no bias and, therefore, the missing answers could be neglected. Accordingly, averages and percentages are based only on those questionnaires with an answer to the particular item.

The questionnaire included a list of 28 items stating potential barriers to adoption of organic farming (Table 1). The respondent was requested to classify each item as either 'a barrier' or 'not a barrier'. For those items classified as a barrier, the respondent was requested to rate it on a four-step scale ranging from '1: very important' to '4: less important'.

The influence of (1) farm type, (2) growing sugar beet and (3) engaging in direct marketing on rating the barriers and the assessment of organic farming was examined. The statistical significance of the differences was tested using the Pearson chi-square test.

Results

Land use and farm characteristics of organic and conventional farms in the study area

On average, the organic farms in the region cultivate more agricultural land than the conventional farms and have a different land-use pattern (see Table 2). Whereas grain and corn (*Zea mays* L.) occupy only 50% of the total arable land of organic farms, conventional farmers devote 64% of their arable land to these crops. Oil seeds are also less important on organic farms (3% versus 11% of the arable land). On the other hand, protein crops such as grain peas (*Pisum sativum* L.) are more important on organic than on conventional farms (7% versus 3% of the arable land). The same holds for vegetables, which occupy 4.2% versus 0.3% of the arable land. Not only is a larger area devoted to these crops, the percentage of farms growing them is nearly twice as high. For example, 35% of organic farms grow vegetables, compared to 4% of conventional farms.

Generally, the number of crops grown is higher on organic farms: the INVEKOS database includes an average of 8.3 crops on organic farms compared to 6.1 crops for conventional farms [for this average, crops such as spring and winter barley (*Hordeum vulgare* L.) were considered different crops].

Regarding grape (*Vitis vinifera*) production, fewer organic farms are involved in viticulture (52% compared to 69%) but the average vineyard size per wine-producer is larger on organic farms (4.5 versus 2.7 ha).

Organic farms are more likely to be engaged in animal husbandry and tend to have more diverse herds (Table 3). However, the relatively low head-count and the fact that only a third of organic farms keep animals, indicates that most do not have animal manure available as a significant source of nutrients for crops. Indeed, only 2.8% of organic farms keep more than 10 head of cattle (*Bos taurus*), and only 5.6% keep more than 10 pigs (*Sus scrofa*), indicating that the vast majority of organic farms keep animals for domestic use and are not commercially involved. On conventional farms, although only 3.2% keep more than 10 head of cattle, 15.9% keep more than 10 pigs.

Since this study focuses on the barriers to adoption of organic farming methods by conventional arable cash-crop farmers, barriers related to animal husbandry will not be discussed.

General information on respondents and their perception of organic agriculture

Farm. The farms included in the survey had an average size of 31.7 ha. Of the 383 respondents, 48% are involved both in viticulture and cropping, while 38% cultivate arable land only and 14% operate vineyards only.

Labor. Of the farm managers who completed the survey, 56% work full-time on their farm, whereas 12% stated that they work less than a quarter of their time on the farm. Only 36% of the farms have available labor other than that of the farm manager and, if applicable, his/her spouse. Non-family labor was hired by only 5% of farms. Labor availability for additional farm activities is therefore limited and might be even more so in the future, since 26% of respondents indicated that they plan to increase their off-farm employment activities.

Direct marketing. Processing and selling farm produce directly to consumers can help to supplement farm family income. A third (31%) of the 355 respondents who answered the question were engaged in direct marketing; however, only 17% declared sales of over US$2000 year^{-1}.

Assessment. Three hundred and sixty farmers indicated their assessment of organic farming (multiple selections were possible):

- 66% considered it a niche for some farms;
- 26% believed it is only for idealists;

Table 1. Potential barriers for conversion to cash crop organic farming.

Full wording of the item (as written in the questionnaire)	Short version
Crop production	
I expect the weed, disease and insect incidence to be too high	Crop weeds, diseases, insects
I expect additional labor requirements to be too high	Additional labor, crop
I expect yields to decrease too much	Decreased crop yields
I expect problems with the nutrient supply	Crop nutrient supply
The necessary changes in crop rotation are prohibitive	Crop rotation
Viticulture	
I expect a too high incidence of diseases and insect pests	Vine diseases and pests
I expect too much additional work	Additional labor, vine
I expect a too high yield reduction	Decreased vine yield
Net income and marketing	
The income depends even more on direct payments	Dependence on direct payments
The price premium for organic produce and the direct payments do not fully cover the additional costs	Prices and payments too low
It is not sure that the crop produce can be sold as organic	Marketed as organic product
I fear a too high decrease in income during the transition years	Lower income during transition
It is not sure that the vine produce can be sold as organic	Marketed as organic wine
If I adopt organic farming, I expect a lower net income in the long term	Lower income in the long term
The marketing of organic products is not sufficiently organized	Market organization insufficient
Overall assessment	
The overall risk of adopting organic farming is too high	Overall risk too high
I expect worse conditions for organic farms in future	Expect worse conditions
Regulations	
I do not want to meet additional documentation requirements	Additional documentation
I do not want the additional on-farm controls	Additional controls
I do not want to fulfill the requirements for marketing of organic produce	Marketing requirements
Structural elements	
The farm succession is not secured	Succession not secured
The continued availability of the leased land is not secured	Land leases not secured
My farm is too small for organic farming	Farm too small
Information and social influences	
The example of organic farms that I know did not convince me	Unconvincing examples
I do not have enough knowledge on organic farming	Lack of knowledge
Not all family members are in favor of a conversion to organic farming	Family not supportive
The advisory services for organic farms are inadequate	Lack of advisory services
Neighbors and friends dissuade from converting to organic farming	Dissuading by neighbors

- 16% believed it is a chance for the survival of Austrian agriculture;
- 11% considered it a fad;
- 9% had no opinion.

Attitude. About half (51.1%) of the 348 farmers who answered the question were undecided regarding a conversion to organic farming. Of the remaining:

- 43.7% would definitely not convert;
- 4.9% were considering a conversion later on;
- 0.3% were to begin conversion the following year.

Changes. Respondents were requested to indicate the changes they expected on their farm, should they convert. The 253 farmers who answered the question selected the following items on the proposed list:

- 74% perceived increased labor requirements;
- 41% believed in an increase in the area devoted to legumes;
- 41% believed it would cause them to discontinue the production of sugar beet (*Beta vulgaris* L.);
- 30% perceived an increased area of set-aside;
- 13% perceived it would cause them to abandon viticulture;
- 21% believed they would have to introduce animal husbandry;
- 11% perceived changes in animal husbandry;
- 10% believed they would have to increase the area devoted to fodder production.

Respondents' rating of the barriers to conversion

The results of the rating for each potential barrier to conversion are presented in detail in Table 4, and the average rating is shown graphically in Figure 1. For ease of interpretation, related items are arranged in groups, e.g., barriers related to crop production or those related to income and marketing. The sequence of the groups in the tables, figure and in the discussion does not indicate an order of importance.

Crop production and viticulture. The two most important concerns for both activities are the anticipated problems of

Table 2. Comparison of land use for the conventional and organic farms in the study area.

Land use/major crops	Average area[1] (ha)		Share of farms[2] (in %)	
	Conventional	Organic	Conventional	Organic
Total agricultural area	25.6	36.2	100.0	100.0
Total arable land	28.3	37.3	83.0	88.7
Barley (*Hordeum vulgare*)	9.4	6.5	73.2	47.9
Wheat (*Triticum aestivum*)	10.1	13.3	67.0	67.9
Sugar beet (*Beta vulgaris*)	4.3	6.2	39.2	5.6
Rape (*Brassica napus*)	5.6	0.0	25.3	0.0
Sunflower (*Helianthus annus*)	4.4	2.5	28.2	11.3
Oil squash (*Cucurbita pepo*)	3.9	4.4	4.0	42.3
Grain peas (*Pisum sativum*)	2.8	5.5	27.8	40.8
Potatoes (*Solanum tuberosum*)	2.0	5.2	17.4	36.6
Vegetables	1.8	4.2	4.0	35.2
Alfalfa (*Medicago sativa*)	0.7	2.7	10.0	40.8
Fallow land	3.5	5.2	67.9	69.0
Grapes (*Vitis vinifera*)	2.7	4.5	68.6	52.1
Permanent grassland	0.9	1.6	18.9	39.4
Other agricultural areas	0.9	0.9	7.1	21.1

[1] The average is calculated by dividing the area by those farms that have arable land or plant a specific crop. Since the values are not averaged for the total number of farms, the individual values do not add up to the total area of arable land or to the total agricultural area.
[2] The share of farms: percentage of farms with a particular land use in the 6515 conventional or 71 organic farms in the study area.
Source: INVEKOS 1999, own calculations.

Table 3. Comparison of animal husbandry of the conventional and organic farms in the study area.

Animal type	Average number[1]		Share of farms[2] (in %)	
	Conventional	Organic	Conventional	Organic
All animal types	–	–	26.3	32.4
Cattle (*Bos taurus*)	23.6	15.1	5.0	9.9
Pigs (*Sus scrofa*)	109.7	16.1	19.6	14.1
Sheep (*Ovis ammon* f. *aries*)	24.5	45.0	1.0	14.1
Goats (*Capra aegagrus* f. *hircus*)	4.9	29.4	1.0	7.0
Chicken (*Gallus gallus domesticus*)	89.9	32.8	12.4	15.5
Horses (*Equus caballus*)	4.7	4.0	1.8	8.5

[1] The average is calculated by dividing the number of heads by those farms that keep the specific animal type.
[2] The share of farms: percentage of farms with a particular animal type in the 6515 conventional or 71 organic farms in the study area.
Source: INVEKOS 1999, own calculations.

weeds, diseases and insects, as well as additional labor requirements. The fear of not being able to manage the additional work requirements is also the most frequently mentioned barrier in the open question requesting information on 'other barriers to conversion'.

Net income and marketing. This group of items is viewed as important, since less than 10% of respondents classify it as 'not a barrier'. Topping the list of income-related items is the apprehension of an increased dependence on compensatory payments.

Overall assessment. In light of the expected changes, i.e., new production methods, new crops, new marketing strategies, and changes in sources of income, it is not surprising that the overall risk of a conversion is rated as too high. Of all items, it was classified as 'a barrier' by the highest number of respondents.

Regulations. The fifth group of barriers in Figure 1 concerns the legal framework of organic agriculture. The farmers who classified these items as a barrier, rated them as quite important. However, 29% of respondents classified the additional documentation as 'not a barrier' and 26% of respondents classified the additional on-farm controls as 'not a barrier'.

Structural elements. Structural elements, such as unsecured succession, unsecured land leases and smallness of the farm, can influence the decision to convert to organic farming. Indeed, only 22% of respondents classified an unsecured farm succession as 'not a barrier'. The 17% of respondents who indicated that they will abandon farming reflect the trend of concentration of agricultural production which is expected to continue as the competition from other EU countries intensifies, new member countries join the EU and global trade is further liberalized.

Table 4. Classification and rating of potential barriers to conversion.

Item	Responses classifying an item as 'a barrier'[1]			Responses classifying an item as 'not a barrier'	
	N	Mean[1]	SD	N	% of all answers
Crop production					
Crop weeds, diseases, pests	237	1.34	0.73	5	2.1
Additional labor, crop	223	1.45	0.82	5	2.2
Decreased crop yields	205	1.71	0.96	13	6.0
Crop nutrient supply	194	2.06	1.04	19	8.9
Crop rotation	171	2.25	1.20	41	19.3
Viticulture					
Vine diseases and pests	160	1.43	0.80	6	3.6
Additional labor, vine	137	1.62	0.94	9	6.2
Decreased vine yield	140	1.86	1.02	12	7.9
Net income and marketing					
Dependence on direct payments	222	1.61	0.89	23	9.4
Prices and payments too low	233	1.66	0.90	17	6.8
Marketed as organic product	196	1.67	0.95	14	6.7
Lower income during transition	229	1.69	0.93	18	7.3
Marketed as organic wine	142	1.73	0.98	8	5.3
Lower income on the long term	228	1.79	0.94	22	8.8
Market organization insufficient	223	2.09	1.07	24	9.7
Overall assessment					
Overall risk too high	240	1.78	0.92	17	6.6
Expect worse conditions	212	2.08	1.03	25	10.5
Regulations					
Additional documentation	187	2.02	1.21	75	28.6
Additional controls	184	2.31	1.22	64	25.8
Marketing requirements	201	2.33	1.19	42	17.3
Structural elements					
Succession not secured	204	1.90	1.21	59	22.4
Land leases not secured	170	2.28	1.28	68	28.6
Farm too small	160	2.59	1.33	107	40.1
Information and social influences					
Unconvincing examples	211	2.13	1.14	41	16.3
Lack of knowledge	203	2.26	1.16	47	18.8
Family not supportive	179	2.41	1.20	68	27.5
Lack of advisory services	188	2.49	1.13	48	20.3
Dissuading by neighbors	143	3.13	1.20	97	40.4

[1] Scale from 1 to 4: 1= very important barrier; 4 = less important barrier.

Information and social influences. Nearly 80% of the respondents noted that their lack of knowledge is a somewhat important barrier. However, the lack of adequate advisory services was not rated as an important barrier. Visits to organic farms as a source of first-hand information did not seem to be a motivating experience, as 84% of respondents saw organic farms they know as 'not a convincing example'. As far as social pressures are concerned, resistance within the family was rated as a more important barrier than the influence of friends.

Influence of the farm type and selected farming activities

The relationship between (1) the attitude towards conversion and (2) the rating of potential barriers to (a) farm type (primarily arable/primarily vineyards/both arable and vineyards), (b) growing/not growing sugar beet, and (c) involved/not involved in direct marketing was analyzed.

Some averages were slightly different, indicating that a relationship between, e.g., the rating of a barrier and the farm type, might exist. However, when tested for their statistical relevance, all differences were non-significant at the 0.05 level, except for the difference between farmers with and without sugar beet in the rating of the barrier 'farm is too small'. This is due to the fact that the average size of those farms growing sugar beet is much larger than the area operated by those who do not plant sugar beet (average 46.1 ha versus 17.9 ha). Thus sugar-beet producers did not rate the size of their farm as an important barrier, while those without sugar beet rated it as more important (average rating: 3.24 versus 2.19).

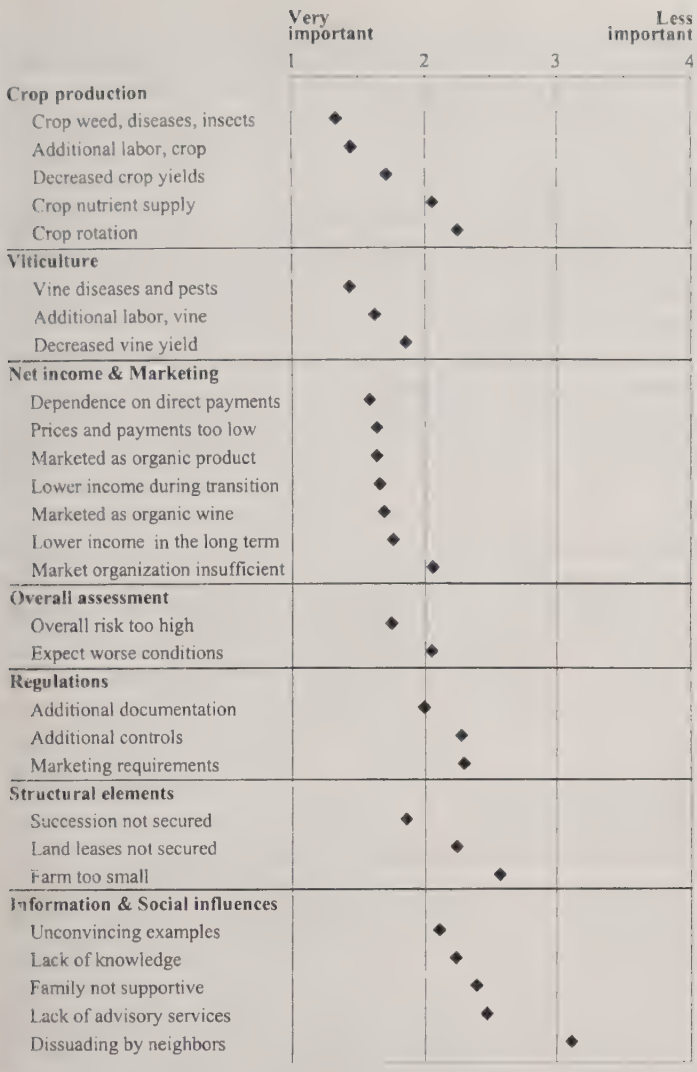

Figure 1. Average rating of the barriers to adopting organic farming by the respondents that classified the item as a barrier.

The available data, therefore, did not allow the establishment of a causal relationship between the selected farm characteristics and the farmers' rating of specific barriers to conversion or his/her general attitude towards organic farming.

influence of the attitude towards a conversion

Farmers who were considering a conversion to organic farming at a later date tended not to rate either the overall risk of a conversion, nor a potential decrease in yield as an important barrier (significant at the 0.01 level). A significant correlation (at the 0.05 level) was also found between these farmers and their rating of three potential barriers as 'not important': unconvincing organic farms, the expectation of worsening conditions for organic farms, and the expectation of too high labor requirements. Since no significant correlation could be found between these farmers and variables such as farm size and available family labor, it would appear that their rating of the barriers might be influenced by personal attitudes and subjective assessments rather than the production factors available to them.

A significant relationship (at the 0.01 level) was also found between the attitude toward a conversion and the assessment of organic farming. Farmers who were either undecided or who definitely would not convert to organic farming tended to perceive it as a 'niche for some farms' (73% and 66%, respectively). On the other hand, of farmers who were considering a future conversion, 59% perceived organic farming as a 'chance for the survival of Austrian agriculture' and the remaining 41% perceived it as a niche.

Discussion of Results in the Context of Other Research Findings

Crop production and viticulture

Responses indicate that conventional farmers are well aware that an adoption of organic farming would necessitate profound changes in their farm organization. The differences in current cropping patterns between conventional and organic farms can give an indication of the changes that might be necessary in the framework of a conversion. However, since the cropping pattern of the organic farms before their conversion is not known, it cannot be ascertained that conventional farms will have the same pattern after conversion as the current organic farms. However, given the requirement for soil fertility maintenance in organic farming without animal manure, it can be assumed that some changes are necessary and that these are more profound for specialized than for diversified conventional farms.

The barriers to conversion rated most important by the respondents were items related to the higher dependence on natural variations and weather conditions and the limited corrective options available compared to conventional agriculture. This has also been reported by other studies in Austria (Kirner and Schneeberger, 2000; Schneider, 2001). The issues related to crop production are all intimately linked, as a higher incidence of weeds or insects can severely reduce yields, which can also result from unbalanced or insufficient nutrient supply. Schneider (2001) reported that farmers were especially concerned about the nitrogen (N) supply. This may be even more so when animal manure is in short supply.

The lack of statistically significant correlations between farm type and the rating of barriers might be somewhat surprising; however, a similar result was reported by Kirner and Schneeberger (2000). A possible explanation is that the influence of farm structural characteristics is superceded by other factors, such as personal characteristics, a hypothesis also proposed by Freyer (1998b) and Kirner (2001).

Labor requirements

In organic farming several factors can lead to increased labor requirements: weed control must be performed mechanically or manually and the production patterns tend to be more diversified. Therefore crops such as sugar beet may have to be abandoned due to the high labor requirement for weed control. Indeed, the increased labor requirement is generally found as a major barrier to adoption (Häfliger and Maurer, 1996; Kirner and Schneeberger, 2000; Loibl, 1999). Sholubi et al. (1997)

emphasized that the timeliness and frequency of field operations such as planting and cultivation is particularly important. This might be a major problem in the study area, as over 40% of the respondents pursue off-farm work. It would seem that not only their total available time is curtailed, but they are also restricted in their flexibility to perform the necessary field work at the optimal time, depending on weather and soil conditions. However, no statistically significant correlation between the rating of labor as a barrier and the amount of time the farm manager works on the farm and the total available family labor, or between the status of part-time or full-time farmer, could be established. It therefore seems that other factors influence the rating of labor as a constraint.

Marketing

The profitability of organic farming is influenced considerably by the ability to secure price premiums. The premium for organic cereals in Austria is around 100% (Michelsen et al., 1999). The lack of adequate processing capacities and/or marketing channels can prevent a farmer from securing the premium for some or all of his/her produce. Farmers are also unsure if the premium will remain at the current level, since most respondents see organic farming as a niche market. The fear of conventional farmers that an increasing supply level will lead to a collapse in price premiums is one of the barriers to conversion listed by Padel and Lampkin (1994). Lockeretz (1999) reports the experience of an organic farmer in Sweden, who stated that although all products are sold at premium prices, the level of this premium is volatile due to a 'thin' organic market. The marketing uncertainty is also mentioned as a barrier to conversion by Loibl (1999). Similar results are reported by Hollenberg et al. (1999) for Germany and by Häfliger and Maurer (1996) for Switzerland.

Income

The economic performance of organic farming depends not only on price premiums, but also on compensatory payments granted to farmers participating in the Austrian Agri-environment Program. These can make up a significant part of farm income, which is reflected in the respondents' fear of an increased dependence on compensatory payments in case of a conversion to organic agriculture. This fear is based mainly on the uncertainty of the future development of compensatory payments in the face of limited EU-budgets to be shared among an increasing number of EU member states. Häfliger and Maurer (1996) report the same issue for Switzerland. In Germany the duration of the compensatory payments is perceived as too short and reported as a barrier to adoption (Hollenberg et al., 1999).

Regulations

The legal basis for organic production in Austria is the EU regulation 2092/91. However, to be eligible for government support, organic farmers must also fulfill the guidelines of the Austrian Agri-environment Program. To certify compliance with these regulations, each organic farmer must accede to yearly inspections carried out by independent, accredited inspection organizations. If the farmer is a member of an organic association, he/she must also observe its statutes. This accumulation of regulations is seen as a barrier to adoption not only by the farmers in the study area but also in Switzerland (Freyer, 1998a) and in Germany (Hollenberg et al., 1999). An aggravating factor is that these various guidelines and regulations are continuously updated and changed, while farmers are required to implement the current version to keep in compliance and avoid fines.

The regulations also require additional documentation to keep track of all purchased inputs (source, type and quantity) and all products sold (type and quantity). The upkeep of this documentation is time consuming and must be presented to the inspector on demand. However, the respondents, although reluctant to devote additional time to paperwork and/or to allow for additional controls, did not rate these certification requirements as major barriers to conversion. These findings contrast with reports from dairy farms in the mountainous regions of Austria, where tight regulations and controls are seen as patronizing and are major barriers to organic farming, even leading some farmers to abandon organic farming (Hadatsch and Milestad, 2001; Schermer, 2001).

Social influences

Family resistance was rated as an important barrier, which might indicate an inter-generational conflict as the parents might be reluctant to agree to a change as far-reaching as the conversion to organic farming. This interpretation is supported by the findings of Duram (1999), Freyer et al. (1994) and Schneider (2001). Pressure by neighbors or friends to remain with conventional farming is not particularly strong, and only about a quarter of respondents viewed organic farming as reserved for 'idealists'. Häfliger and Maurer (1996) report that the negative attributes that were attached to organic farmers in the early eighties have been replaced by a general acceptance. Hollenberg et al. (1999) also report that the negative image of organic farming is no longer an important barrier to conversion.

Conclusions

Although a large-scale conversion is not likely, a sizable minority of conventional farmers are considering organic farming as an option for the future. Farm structural variables had little influence on this attitude and the rating of barriers. It therefore seems that the choice between conventional and organic farming is multidimensional, resulting from complex interactions between various factors, and cannot be reduced to the presence or absence of specific farm characteristics. Personal determinants, such as subjective perception and future expectations, of farm managers seem to play an important role in farming decisions as fundamental as the conversion to organic agriculture. Further research on the type of farmers most likely to convert, as well as their motives, would help in the design of targeted policies to promote conversion.

Several measures should be implemented to increase the intrinsic attractiveness of organic farming and its competitiveness with conventional farming. On the one hand, the risk of conversion could be decreased by ensuring more stability and homogeneity in the regulatory framework and improving the marketing channels. On the other hand, a better understanding of organic farming and its systematic principles could be promoted by targeting both farmers and consumers. Indeed, the risk of future reductions in producer prices due to an increasing supply of products could be decreased by heightening consumer awareness of the merits of organic products and production methods. This would secure an ongoing high demand and stable price premiums, which in turn would be an important incentive for farmers who are reluctant to rely excessively on compensatory payments for the economic survival of their farms.

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Killing cover crops mechanically: Review of recent literature and assessment of new research results

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Abstract. *Cover-crop residues left on the soil surface as a mulch in no-till crop production systems protect the soil from erosion, increase water infiltration and suppress weeds. Because many growers using cover crops want to reduce chemical inputs, non-chemical methods of killing or suppressing cover crops are needed. In the first part of this paper we review the current literature and discuss advantages and disadvantages of five mechanical methods for killing cover crops, i.e., mowing, rolling, roll-chopping, undercutting and partial rototilling. We also report on three new studies that broaden the current literature, including planting into freshly killed residue. In the first study, the use of planter attachments to remove surface residues from the planter row improved stands when cotton was no-till planted 2–7 days after mowing cover crops in Mississippi. In the second study, 100% of a rye/vetch cover crop in Missouri was killed by mowing, and greater than 90% was killed by roll-chopping. Cotton stands were reduced by the use of row cleaners that clogged when the cover crop was roll-chopped or mowed on the same day that the crop was planted. The third study evaluated three methods of mechanically killing summer cover crops in North Carolina. Undercutting provided greater than 95% kill for five of six broadleaf species, and two of five grass species. Mowing effectively killed all six broadleaf cover crops, but re-growth occurred with three of five grasses, with the exception of nearly mature German foxtail millet and mature Japanese millet. In general, rolling did not effectively kill broadleaf or grass cover crops, with the exception of nearly mature German foxtail millet, mature Japanese millet and mature buckwheat.*

Key words: crop residues, living mulches, mowing, no-tillage, partial rototilling, rolling, roll-chopping, undercutting

Introduction

Cover crops are used in cropping systems to enhance biological mechanisms and to serve as potential substitutes for chemical inputs. These can be tilled into the soil before planting cash crops, or killed and left on the soil surface as a mulch in no-till crop production. Leaving cover crops as surface mulches in no-till crop production systems has the advantage of conserving soil moisture (Morse, 1993), reducing soil erosion (Langdale et al., 1991), improving soil physical properties (Blevins and Frye, 1993), in some cases, suppressing weeds (Creamer and Baldwin, 2000; Creamer et al., 1996; Teasdale, 1993), inhibiting insects (Zehnder and Hough-Goldstein, 1990), reducing disease (Ristaino et al., 1996) and increasing crop yields (Triplett et al., 1996). In most studies, cover crops managed as no-till mulches have been killed with glyphosate (*N*-[phosphonomethyl]glycine), paraquat (1,1′-dimethyl-4,4′-bipyridinium ion) (Bauer and Reeves, 1999; Raimbault et al., 1990; Reeves et al., 1993; Sarrantonio and Scott, 1988) or mixtures of non-selective post-emergence and pre-emergence herbicides (Teasdale and Shirley, 1998). Because many growers often want to reduce use of chemical inputs, non-chemical methods of killing or suppressing cover crops are desirable.

Mechanical methods of managing cover crops and leaving them on the soil surface include mowing, rolling, roll-chopping, undercutting and partial rototilling. Generally, the success of these methods is dependent, in part, on the species and growth stage of the cover crop. At certain growth stages, mechanical management can produce rapid desiccation and create an opportunity for utilizing cover-crop residues for weed control. Even where mechanical treatments are inadequate, herbicide requirements for adequate control are often reduced.

In this paper we review the current literature relevant to the management of cover crops with mechanical methods and present new findings that broaden our knowledge base.

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Literature review

Mechanical methods

Mowing. Mowing has been one of the most common methods used by growers to mechanically kill cover crops and leave their residues as surface mulches. For example, Derpsch et al. (1986) reported on successful no-till cropping systems in Brazil (23°S) in which individual cover crops were killed by cutting with a

Table 1. Percent kill by flail mowing various winter annual cover crop species in Louisiana, Mississippi and Ohio.

Location/cover crop	Scientific name	Growth stage	Date of kill	Percent kill
Louisiana[1]				
Austrian winter pea	*Pisum sativum* L.	<10% bloom	Mid April	86
Rough pea	*Lathyrus hirsutus* L.	<10% bloom	Mid April	82
Hairy vetch	*Vicia villosa* Roth	<10% bloom	Mid April	95
Big flower vetch 'Woodford'	*V. grandiflora* Scop.	Seed development	Mid April	61
Common vetch 'Cahaba White'	*V. sativa* L.	<50% bloom	Mid April	85
Crimson clover 'Tibbee'	*Trifolium incarnatum* L.	Seed development	Mid April	95
Berseem clover 'Bigbee'	*T. alexandrinum* L.	Vegetative	Mid April	27
Red clover 'Chesapeake'	*T. pratense* L.	<50% bloom	Mid April	11
Ball clover 'Segrest'	*T. nigrescens* Viv.	<50% bloom	Mid April	44
Arrowleaf clover 'Amclo'	*T. vesiculosum* Savi	<10% bloom	Mid April	59
Subterranean clover 'Mt. Barker'	*T. subterraneum* L.	Full bloom	Mid April	27
Subterranean clover 'Woogenellup'	*T. subterraneum* L.	Seed development	Mid April	18
Cutleaf evening primrose (volunteer)	*Oenothera laciniata* Hill	<50% bloom	Mid April	18
Wheat 'Coker 916'	*Triticum aestivum* L.	Heading	Mid April	90
Annual ryegrass 'Gulf'	*Lolium multiflorum* Lam.	<50% bloom	Mid April	15
Mississippi[2]				
Hairy vetch	*Vicia villosa* Roth	Vegetative	Early April	94
		Vegetative	Mid April	91
		10–20% bloom	Early May	99
Crimson clover 'Tibbee'	*Trifolium incarnatum* L.	10% bloom	Early April	87
		Full bloom	Mid April	88
		Seed development	Early May	99
Subterranean clover 'Mt. Barker'	*T. subterraneum* L.	<50% bloom	Early April	41
		Full bloom	Mid April	45
		Seed development	Early May	90
Berseem clover 'Bigbee'	*T. alexandrinum* L.	Vegetative	Early April	64
		Vegetative	Mid April	52
		Early bloom	Early May	93
Ohio[3]				
Hairy vetch	*Vicia villosa* Roth	Early bud	27 April 1990	19
		Mid bloom	24 May 1990	93
		Full bloom	18 June 1990	100
		Early bud	30 April 1991	74
		Mid bloom	11 May 1991	100
		Full bloom	June 1991	100

[1] Source: Dabney and Griffin (1987).
[2] Source: Dabney et al. (1991).
[3] Source: Hoffman et al. (1993).

rotary mower at flowering, followed by planting of corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.] or kidney bean (*Phaseolus vulgaris* L.). In these systems, white lupin (*Lupinus albus* L.) and hairy vetch (*Vicia villosa* Roth) provided the most benefit for corn, black oat (*Avena strigosa* Schreb.) for soybean, and black oat and oilseed radish (*Raphanus sativus oleiferus* L.) for kidney bean. These cover crops all increased crop yields compared with soils covered with volunteer vegetation during the winter.

Generally, a flail-type mower is preferred over a bush-hog or other rotary-type mower because it leaves cover-crop residues uniformly distributed on the soil surface. Bush-hog mowers tend to leave uneven residue clumps, resulting in less desirable conditions for planting and weed suppression. Also, rotary mowers do not cut as close to the soil surface as flail mowers, so regrowth of cover crops is more likely (Dabney et al., 1991). A sickle-bar mower can be used for some types of cover crops. It severs the cover crop at its base, rather than shredding it into fine pieces. This can yield a thicker, longer-lasting surface mulch and can reduce weed growth (Creamer et al., 1995). However, a sickle-bar mower can be difficult or impossible to use on a viny cover crop, such as hairy vetch, due to tangling in the blades (Creamer et al., 1995). A reel-assisted sickle mower will better handle these conditions if it can be adjusted to avoid creating a windrow. A disk mower can cut close to the surface and through viny crops more efficiently than a sickle-bar mower, but it tends

Table 2. Growth stage of wheat and rye at mowing, and biomass of the regrowth 4 and 8 weeks after mowing in 1992 and 1993 in Ne York.[1]

	1992			1993		
		Biomass (kg ha^{-1})			Biomass (kg ha^{-1})	
Cover crop	Growth stage	4 WAM[2]	8 WAM	Growth stage	4 WAM	8 WA
Wheat	First node	2100 a[3]	5320 a	First node	1770 a	5470 a
	Second node	300 b	970 b	Flag leaf	560 b	2240 b
	75% head	90 c	90 c	In boot	450 b	1280 b
	Milky kernel	40 d	10 d	Watery kernel	20 c	20 c
Rye	First node	4340 a	8470 a	Second node	900 a	2820 a
	In boot	200 b	780 b	In boot	610 a	910 b
	100% head	10 c	30 c	100% head	110 b	280 c
				Watery kernel	10 c	0 c

[1] Source: Wilkins and Bellinder (1996).
[2] Weeks after mowing.
[3] Letters denote mean separation within column, year and species using Waller–Duncan *t*-test, *k* ratio = 100. Plant biomass logarithmically transformed before mean separation.

to leave residue in strips separated by bare areas rather than evenly distributed over the surface.

Results from studies in Louisiana, Ohio and Mississippi investigating the effectiveness of mowing various cover-crop species are summarized in Table 1. Generally, erect-growing or stemmy winter annual broadleaves were killed easily by mowing, although there was a trend for increased kill at later stages of cover-crop growth. Grass cover crops, as compared to broadleaves, were more difficult to kill by mowing.

In the Louisiana study by Dabney and Griffin (1987), cutleaf evening primrose (*Oenothera laciniata* Hill), a weed that dominated the site when a cover crop was not planted, was not killed by mid-April flail mowing. However, most of the cover crops excluded this weed, and could be controlled by mowing. The cover crops with at least 90% kill ratings from mowing included hairy vetch, crimson clover (*Trifolium incarnatum* L.) and wheat (*Triticum aestivum* L.) (Table 1). The authors concluded that mowing could be an economic alternative to herbicides for killing some cover crops. Cover crops that were poorly controlled by mowing included berseem clover (*Trifolium alexandrinum* L.) in the pre-flowering stage, annual ryegrass (*Lolium multiflorum* Lam.) not headed, red clover (*Trifolium pratense* L.) approaching full bloom, and subterranean clover (*Trifolium subterraneum* L.) having stems below the cutting height.

In a study by Dabney et al. (1991) in northern Mississippi, effectiveness of mowing 'Tibbee' crimson clover, 'Mt. Barker' subterranean clover, 'Bigbee' berseem clover, and hairy vetch during early April, mid April, and early May was evaluated for 2 years. Mowing was accomplished with a flail mower set 3.81 cm above ground. Mowing gave a 90% or better kill of hairy vetch (Table 1). When hairy vetch stems exceeded 61 cm in length and at least 36 cm of stem was decumbent on the soil surface, close mowing killed vetch regardless of the reproductive growth stage. For the other cover crops, percent kill increased as cover-cro maturity increased. When the mower was mistakenly raised t 6.4 cm (versus 3.8 cm) for the mid-April mowing in one year, th percent kill dropped markedly compared to the previous year (8 versus 95% for hairy vetch, 78 versus 91% for crimson clove 41 versus 49% for subterranean clover, and 23 versus 79% fo berseem clover).

In an Ohio study by Hoffman et al. (1993), hairy vetch wa flail mowed at early bud, mid bloom and late bloom in each of years. Control was better at later growth stages in both years The vetch was not completely suppressed by mowing at the earl bud stage (late April in Ohio), particularly in 1990, but at leas 90% was killed by mowing in mid May or later (Table 1 Percent kill of hairy vetch at the earliest kill date was greater i 1991 due to drought conditions. Similarly, Teasdale (1993 reported that hairy vetch regrowth after mowing was greater i years when the vetch was less mature and had less biomas because of later fall hairy vetch planting dates or earlier sprin kill dates.

Wilkins and Bellinder (1996) conducted an experiment t determine the regrowth biomass of winter wheat and rye (*Secal cereale* L.) that were mowed with a sickle-bar mower to a heigh of 10 cm when each was at various growth stages. In their study each crop was mowed four times, beginning when the cro reached the first elongated internode growth stage (early May and continuing at 2-week intervals. Regrowth biomass wa measured at 4 and 8 weeks after mowing, by clipping the ne growth above the mulch layers. Plant height and growth stage o the regrowth were measured 8 weeks after mowing (WAM Table 2 shows the growth stage at each mowing date and th amount of regrowth at 4 and 8 WAM. Depending on mowin date, regrowth occurred from different plant parts. Before th boot stage, regrowth came from undamaged tillers. After th boot stage, regrowth was produced from secondary till

Table 3. Percent kill by rolling (Mississippi) and rolling or roll-chopping (Ohio) of various broadleaf winter annual cover crop species.

Cover crop	Growth stage	Date of kill	% Kill	
			At coulter spacing 10.2 cm	At coulter spacing 20.3 cm
Mississippi[1]				
Hairy vetch	Vegetative	Early April	80	62
	Vegetative	Mid April	90	73
	10–20% bloom	Early May	99	98
Crimson clover 'Tibbee'	10% bloom	Early April	44	23
	Full bloom	Mid April	83	56
	Seed development	Early May	93	81
Subterranean clover 'Mt. Barker'	<50% bloom	Early April	26	16
	Full bloom	Mid April	26	21
	Seed development	Early May	61	42
Berseem clover 'Bigbee'	Vegetative	Early April	20	13
	Vegetative	Mid April	31	26
	Early bloom	Early May	53	35
			Roll	**Roll-chop**
Ohio[2]				
Hairy vetch	Early bud	27 April 1990	0	–
	Mid bloom	24 May 1990	56	–
	Late bloom	18 June 1990	97	–
	Early bud	30 April 1991	63	47
	Mid bloom	11 May 1991	87	95
	Late bloom	05 June 1991	99	99

[1] Source: Dabney et al. (1991).
[2] Source: Hoffman et al. (1993).

elongation. After heading, regrowth of both species was limited. The authors suggest that the efficacy of mowing to kill cereal cover crops may be improved by: (1) fall seeding that favors earlier flowering; (2) high seeding rates that cause fewer tillers per plant; (3) consistent planting depth for uniform growth; and (4) nutrient-poor soil during early spring, which reduces the ability of cover crops to recover and renew vegetative growth (Wilkins and Bellinder, 1996).

Rolling and roll-chopping. Mowing may not be the best option for mechanically killing cover crops to optimize weed suppression. The small pieces generated with flail or rotary mowing decompose rapidly, as they have more surface area and are in closer contact with soil microorganisms. Rolling lays the cover crop down intact, flat on the surface, and can be accomplished in various ways, as described below. Roll-chopping is more aggressive than rolling. A variety of designs exist where blades are attached to the roller to cut the cover crop into large sections as it is rolled. Rolling and roll-chopping cover crops, as compared to mowing, creates a longer-lasting surface mulch with longer weed suppression potential. Rolling also has the advantage over mowing of being accomplished at higher speeds, with lower machinery maintenance costs and reduced fossil fuel consumption. Various methods have been used for rolling and roll-chopping cover crops. Depending on conditions, kill can result from breaking, cutting, crushing or crimping stems.

In a study by Morse (1995), in Virginia, well-developed summer cover crops of buckwheat (*Fagopyrum esculentum* Moench) and German foxtail millet [*Setaria italica* (L.) P. Beauv.] were either rolled with a 1.8-m (6-foot) mower on 23 August 1994, just prior to no-till transplanting broccoli (*Brassica oleraceae* L. var. *capitata*). Rolling was accomplished by pulling a disengaged flail mower (weighing approximately 385 kg) across the plots. When the cover crops were rolled, buckwheat had flowered and developed viable seed, foxtail millet had flowered and set immature seed and soybean was in early flower. Rolling effectively killed foxtail millet and buckwheat, but not soybean. Soybean residues remained green but did not interfere with broccoli production. However, some 5% of redroot pigweed (*Amaranthus retroflexus* L.) did survive rolling.

In a study in Mississippi, Dabney et al. (1991) achieved successful rolling of cover crops using a no-till grain drill with 20-cm coulter drill spacing. In one treatment, extra coulters were added between each drill to create 10-cm coulter spacing (Table 3). With this equipment, stems were cut in the direction of travel rather than perpendicular to that direction, as occurs with a roll-chopper. As expected, closer coulter spacing was generally more effective at killing cover crops than wider coulter spacing, and there was a trend for increased kill at later kill dates. As with mowing, hairy vetch control in this study was more related to stem length than to growth stage. Vetch kill by rolling with the 10-cm coulter spacing was more than 90% when stem length

exceeded 61 cm. With this stem length, canopy height was only about 28 cm. The rest of the stem lay along the ground, where it was cut by the rolling coulters. In contrast to its utility for vetch, rolling was not an effective kill method for subterranean or berseem clovers at any growth stage evaluated. However, rolling did increase susceptibility of the crops to subsequent herbicide applications (Dabney et al., 1991).

In a study by Hoffman et al. (1993), hairy vetch was rolled at early bud, mid bloom and late bloom growth stages (Table 3). Rolling was accomplished with either a smooth, 60-cm diameter, 270-kg, water-filled turf roller, or a 410-kg, water-filled drum roller with full-width steel blades attached (effectively a roll-chopper), similar to that illustrated by Derpsch et al. (1988). Rolling or roll-chopping were more effective at later kill dates than at the early kill dates. In 1990, rolling at early bud stage did not kill the vetch; however, in 1991, a dry year, rolling was more effective. Rolling or roll-chopping at late bloom killed at least 97% of the vetch.

Undercutting. Creamer et al. (1995) designed an undercutter to sever cover-crop roots and flatten the intact, above-ground biomass on the surface of raised beds. The undercutter was designed to kill the cover crop with minimal soil disturbance, while leaving the maximum amount of cover-crop residue on the soil surface. It was developed to improve mechanical control of cover crops without shredding the residue. The standards holding the undercutting blades are placed on the outside of the bed to prevent soil and residue disturbance. A rolling basket follows the blades to flatten and evenly distribute the undercut cover crop, and to aid residue flow through the undercutter.

The undercutter was evaluated in 1992 to determine its effectiveness in killing 17 species of cover crops at two locations in Ohio. Whether a cover-crop species was killed by the undercutter depended primarily on growth stage (Creamer et al., 1995). Rye, hairy vetch, bigflower vetch (*Vicia grandiflora* Scop.), crimson clover, barley (*Hordeum vulgare* L.) and subterranean clover were in mid to late bloom or beyond, and were killed easily. Ladino clover (*Trifolium repens* L.), red clover, yellow blossom sweetclover (*Melilotus officinalis* Lam.), white blossom sweetclover (*Melilotus albus* Medik.), tall fescue (*Festuca arundinacea* Schreb.), orchardgrass (*Dactylis glomerata* L.), annual ryegrass and perennial ryegrass (*Lolium perenne* L.) were not killed (Creamer et al., 1995).

Successful operation of the undercutter depends on proper soil moisture conditions. This reliance can impede timeliness of cultural operations in the field. The current design consists of one blade (a motor-grader blade turned upside down) designed to cut a 1.5-m wide raised bed. This design has been successful on a wider variety of soil types than the original design with two undercutting blades. Undercutting cover crops, as compared to mowing, leaves a thicker, longer-lasting mulch on the soil surface, and a looser soil that can facilitate transplanting of vegetable crops (Creamer et al., 1995). Undercutting to kill cover crops, as compared to rolling, is a slower operation and requires more horsepower.

Partial rototilling. In living mulch systems, partial rototilling has been shown to be an effective suppression technique for stoloniferous cover crops. In New York, intercropped Dutc white clover (*Trifolium repens* L.) was partially rototilled i sweet corn. Although mowing did not sufficiently suppress th clover, it was effectively suppressed by rototilling well established clover 2 weeks after corn emergence. Strips c clover roots were left between the tines, resulting in extensiv regrowth later in the season. The intercropping system enhance corn nitrogen nutrition under low nitrogen fertility (Grubinge and Minotti, 1990).

Other impacts of mechanical kill methods

Where residues are heavy and crops are grown in cooler part of their regions of adaptation, residue removal can result i earlier soil warming, more rapid crop growth and higher yield of no-till planted crops (Kaspar and Erbach, 1998). Cover crop can increase the amount of residue cover, and therefore, increas the benefits of row cleaners (Janovicek et al., 1997).

The method of cover-crop kill has been shown to affect insec populations. Populations of armyworm (Lepidoptera: Noctuidae were lower (Laub and Luna, 1991), and those of its natura enemies (*Pterostichus* spp. and *Scarites* spp. [Coleoptera Carabidae]) and wolf spiders (Aranea: Lycosidae) highe (Laub and Luna, 1992), in mowed cover-crop plots as compare with herbicide-treated plots. The authors theorized that th mulch created by mowing provided a more favorable habitat fo predators, and that mowing also placed armyworm larvae in location more susceptible to soilborne predators.

The method of cover-crop kill can also affect weeds tha emerge through the killed cover-crop mulches. Regrowth of th cover crop and germination and growth of small weeds in th understory of the cover crop are both a concern. Weeds are mor suppressed by living cover crops than by dead cover-cro mulches (Teasdale, 1993). Leaving the cover-crop materia intact on the surface, by undercutting or sickle-bar mowing yielded fewer weeds than when it was chopped into fine piece with a flail mower (Creamer et al., 1995). The finely choppe cover crop was less thick, allowing more light to reac germinating weed seedlings. In addition, a finely choppe cover decomposes more rapidly than a thick, intact mulch as it i in closer contact with soil microorganisms. This may result i longer-lasting weed suppression by intact mulches.

Materials and Methods

Mechanical cover-crop management systems (includin establishment of cash crops into the residue) were evaluated i a combination of replicated-plot and on-farm trials in norther Mississippi (34°N), the Missouri bootheel (36°N) and Nort Carolina from 1993 to 1996. In Mississippi, hairy vetch, 'Elbon rye or rye/vetch mixtures were flail mowed at five differen times, ranging from 0 to 26 days before no-till cotto (*Gossypium hirsutum* L.) was planted in early May in each o the 3 years. No-till planting occurred on 14 May 1993 at 2 seeds m^{-1}, 10 May 1994 at 20 seeds m^{-1}, and 5 May 1995 at 1 seeds m^{-1}. Three-row plots were used to compare cotton stan establishment, using either standard bubble coulters, c

Table 4. Stand of cotton no-till planted after mow-killing cover crops, as affected by planter and attachments and surface residue biomass at planting (Mississippi, 1995).

	Number of cotton plants m^{-1}		
Mowing time:	**<2 days before planting**	**6–8 days before planting**	**>14 days before planting**
Attachment			
Bubble coulter	6.2 a[1,2]	4.9 b	11.2 c
Acra-plant	3.9 a	10.5 bc	10.2 bc
Martin	10.5 bc	10.5 bc	11.5 c
Yetter	9.5 bc	11.2 bc	11.5 c
	Surface residue dry weight at cotton planting (Mg ha^{-1})		
Mowing time:	**<2 days before planting**	**6–8 days before planting**	**>14 days before planting**
Cover crop			
Rye	1.89 ab	1.52 ab	1.06 a
Rye + vetch	4.00 d	2.04 abc	1.74 ab
Vetch	3.26 cd	2.55 bc	1.51 ab

[1] Averaged over 3 years and cover crops.

[2] Means followed by different letters are significantly different ($P < 0.05$). Note that LSDs vary within and between rows and columns so that some numerically similar differences may have different statistical significance.

commercial tined-wheel row cleaner planter attachments mounted on a John Deere 7300 series no-till planter. In the first year, a Martin Row Cleaner (15-inch interlocking spoked wheels; Martin Industries, Elkton, KY) was compared to the bubble coulter. In the second and third years, the Acraplant Zone Manager (interlocking machined fingers attached to central hubs; ACRA-Plant, Garden City, KS) and Yetter Residue Manager (13-inch spoked wheels mounted on either side of a ¾-inch wavy coulter; Yetter Manufacturing, Colchester, IL) attachments were also evaluated. The cotton stand was determined from the center row of the plots 4 weeks after planting. In 1994 and 1995, gravimetric soil water content in the top 75-mm soil depth was determined at planting and, in 1995, surface residue biomass was measured from duplicate areas (each 0.1 m^2) of each plot. Statistical analysis of variance was conducted using Proc Mixed (SAS Institute, 1996).

Cotton stands were assessed in hairy vetch/rye covers that were killed in different ways in a replicated on-farm trial in Braggadocio, Missouri, in 1996. Cover-crop mixtures were killed by either disking, flail mowing or rolling with a stalk chopper. Plot size was 8 rows wide by 92 m long. The cover crop was either tilled into the soil 3 weeks prior to planting, or was rolled or mowed the same day as planting, on 22 May 1996. Rolling was accomplished with a reel pulverizer (rolling stalk chopper) that comprises the front end of a 'do-all' (Forrest City Machine Works, Forrest City, AR), a secondary tillage implement used commonly in the southern US. A combination of a rolling stalk chopper and harrow, a do-all breaks up clods, levels ridges and prepares a seedbed. In this study, the rear harrows were removed before using the front stalk chopper, so that the cover-crop residues would not drag. The stalk chopper consisted of an array of five blades attached to a central bearing to form a reel 46 cm in diameter. When pulled through the field, it rolled down the rye/vetch cover crop and crimped the stems every 29 cm. The tool cut completely through the stems on the tops of the bedded rows, but cutting was incomplete in the lower row middles. Control in these areas was less complete than from flail mowing, but there was little regrowth or crop competition, possibly because of planter and tractor wheel traffic. Each plot was subdivided into 4-row subplots and replicated four times, with treatments being with or without Martin Row Cleaners attached to a Case/International Early Riser planter. Cotton stands were determined 4 weeks after planting.

The effectiveness of mowing, rolling or undercutting summer cover crops was assessed in Plymouth, North Carolina, during September 1995. In North Carolina, summer cover crops have the potential to be incorporated into cropping systems between spring and fall vegetable crops. Plots consisted of three 1.5-m wide raised beds each 6.1 m long, split by method of cover-crop kill and replicated four times. Eleven different summer cover crops were treated on 1 September 1995, and percent kill was rated visually 3 weeks later. A 1.5-m wide flail mower was used for the mowing treatment. Undercutting was accomplished with the implement described in the literature review, while rolling was accomplished by lifting the blades of the undercutter out of the ground and placing downward pressure on the rolling basket. Data were subjected to analysis of variance, and least-significant difference (LSD) tests were used to separate means (SAS Institute, 1989).

Results and Discussion

In Mississippi, when the standard bubble coulter was used, cotton stands improved if planting was delayed at least 2 weeks after mowing the cover crops (Table 4). All functioning row cleaners that removed residues from in front of the planter's

double-disk openers caused less 'hairpinning' of residues than did standard bubble coulters, and this improved the cotton stands. The Martin and Yetter planters improved stands when cotton was no-till planted 2 or fewer days after mowing cover crops. In contrast, the Acraplant attachment quickly became plugged with fresh cover-crop residues and stopped turning, resulting in seed drop on the soil surface, and thus, reduced stands. Although the row cleaners differed in their ability to handle cover-crop residues without plugging, all worked effectively when residues were dry and brittle. With reference to the Missouri study discussed below, none of the row cleaners was satisfactory when cover-crop residues were heavy and fresh.

In the Mississippi study, mowing at the earliest date (14–19 April) allowed regrowth of rye and vetch; moreover, some winter weeds resumed growth so that these plots had green vegetation by planting time each year (data not shown). At later dates, mowing killed both rye (heading) and vetch (vegetative). Mowing also caused rapid drying of cover-crop residues. Because of rainfall during the month preceding planting (113 mm in 1994 and 140 mm in 1995) there were no significant differences in gravimetric soil water content at cotton planting between cover-crop kill dates (average 0.24 g/g in 1994 and 0.26 g/g in 1995). Residue cover on the soil surface increased as the interval between cover-crop mowing and planting was reduced (Table 4). This trend is due both t termination of growth by mowing and residue decompositio after mowing.

In the Missouri field study (Table 5), the Martin Rov Cleaners did not work on a large scale when mowing an planting were done the same day, because they becam wrapped with the moist and flexible vegetation. In this study no-till cotton stands were improved by using the plante without the row cleaner in areas where the rye/vetch cove crop was roll-chopped rather than mowed. Residues oriente in the direction of planter travel were more easily displace by the planter's double-disk opener than where the cove crop had been mowed. Similarly, in the Mississippi study, a additional treatment conducted only in 1993 showed that us of the bubble coulter prior to mowing resulted in a bette stand (9.5 plants m^{-1}) than planting after mowing (Table 4) possibly because there was less randomly oriented mulch o the soil surface. Ratings made 4 weeks after planting showe 100% kill of the cover crop from tillage or mowing, an 90% kill from roll-chopping (data not shown).

Table 6 shows percent kill of 11 summer cover crops rate 3 weeks after treatment in the 1995 North Carolina study. I general, undercutting greatly improved mechanical killing o all the broadleaf cover crops not killed by rolling alone an provided greater than 90% kill for five of the six broadlea cover crops. Grass cover crops were better controlled b undercutting, except for the two species that were killed b all three methods. Without exception, the broadleaf cove crops were easily killed by mowing, even in the vegetativ stage. Pearl millet [*Pennisetum glaucum* (L.) R.Br.], sor ghum-sudangrass [*Sorghum bicolor* (L.) Moench × *Sorghum sudanense* (Piper) Stapf] and sudangrass (*Sorghum sudanens* L.) initiated regrowth 3 weeks after mowing. Mowing kille Japanese millet [*Echinochloa frumentacea* (Roxb.) Link] tha had already formed mature seed, and German foxtail mille in the green seed stage. Rolling provided little control of th summer cover crops, except for nearly mature German foxtai millet, mature Japanese millet and mature buckwheat

Table 5. Stand of cotton planted after tilling, mowing or roll-chopping a rye/vetch cover crop in Braggadocio, Missouri, in 1996.

	Plants m^{-1} 4 weeks after planting	
Management	**Row cleaner**	**No row cleaner**
Till	10.5	10.2
Mow	6.2	7.8
Roll-chop	6.9	9.2

LSD (0.05) = 2.3.
Cover crop biomass: 5.6 ± 0.3 Mg ha^{-1}.

Table 6. Percent kill of various summer cover crop species by mowing, undercutting, or rolling in North Carolina in 1995.

Cover crop	Scientific name	Growth stage	Mow	Undercut	Rol
Broadleaves					
Cowpea 'Iron clay'	*Vigna unguiculata* (L.) Walp.	Vegetative	98	85	
Sesbania	*Sesbania exaltata* (Raf.) Rydb. ex A.W. Hall	Vegetative	100	100	3
Lablab	*Lablab purpureus* (L.) Sweet	Vegetative	96	98	2
Velvetbean	*Mucuna deeringiana* (Bort) Merr.	Vegetative	100	95	5
Soybean 'Young'	*Glycine max* (L.) Merr.	Early bloom	100	99	1
Buckwheat	*Fagopyrum esculentum* Moench	Mature seed	100	100	10
Grasses					
Pearl millet	*Pennisetum glaucum* (L.) R.Br.	Heading	0	73	1
German foxtail millet	*Setaria italica* (L.) P. Beauv.	Green seed	100	100	10
Japanese millet	*Echinochloa frumentacea* (Roxb.) Link	Mature seed	100	100	10
Sudangrass	*Sorghum sudanense* L.	Green seed	0	84	2
Sorghum-sudangrass	*Sorghum bicolor* (L.) Moench × *Sorghum sudanense* (Piper) Stapf	Mature seed	0	89	2

LSD (0.05) = 54.

Although cowpea [*Vigna unguiculata* (L.) Walp.] was easily killed in this study, considerable regrowth occurred when mowed in 1997 and undercut in 1998 2 weeks earlier in the season (Creamer, unpublished data).

Summary

Many summer and winter cover crops can be effectively killed using mechanical methods other than tillage or with herbicide application. Winter annual broadleaves and grass cover crops can be effectively killed by mowing, although there is a trend for increased kill at later growth stages, and, in the case of hairy vetch, with longer stem lengths. Lower mower height can also increase kill. Summer annual grasses, as compared to winter annuals, are more difficult to kill by mowing. However, depending on the time of year and cash crop, regrowth of the cover crop may not reduce yields of the cash crop. Mowing is an attractive management option because most growers already have mowers on their farms. However, mowing generates small residue pieces that decompose quickly, and thus may result in less weed suppression by the cover-crop residue. Flail mowing, as compared to other mowing methods, distributes plant residues more evenly, lessening subsequent planting difficulties and enhancing weed suppression. Because cover crops frequently have considerable decumbent stem length on the soil surface, a low cutting height usually improves cover-crop kill by mowing, unless the soil surface is not level. When a cover crop is mowed, the pieces lie on the ground in a random orientation, and double-disk planter openers are likely to hairpin some pieces in with the seed. Where residues are dry, the use of row cleaner planter attachments that move the residue away from the drill can reduce this problem and improve stands of direct-seeded crops.

Although rolling alone is sometimes not an effective method of cover-crop kill, roll-chopping has increased effectiveness and has several potential advantages over mowing. Rolling or roll-chopping provides a more persistent mulch, and orients the residues to facilitate planting. Both rolling and roll-chopping are also faster, and therefore less expensive, than mowing. It is often recommended that no-till planting into herbicide-killed cover crops be delayed for several weeks after treatment to avoid stand establishment problems (Dabney et al., 1996; Teasdale and Shirley, 1998). This delay reduces the weed control benefits that may be obtained from the cover-crop mulch subsequent to planting, and may possibly be shortened with rolling. Assessing the benefits of integrated management systems that use no-till seeding and direct transplanting prior to or after rolling cover crops warrants more research.

Undercutting has many of the same advantages as rolling and roll-chopping; however, it is more dependent on soil moisture conditions, and thus, timeliness of cultural operations may be an issue. As compared with rolling, undercutting requires more horsepower and the operation is slower. In the studies reviewed herein, undercutting was more effective than rolling in killing both broadleaf and grass cover crops. The soil is loosened by the operation, which may facilitate subsequent transplanting and early growth of vegetable crops.

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The mirage of genetic engineering

T.S. Cox

Introduction

The extensive adoption of transgenic plants now under way has provoked heated debate about its effects on human health, rural life and the environment. But too many critics are neglecting to zero in on transgenic technology's Achilles heel: its inherent inability to deliver on its promises. Longstanding theory and practice predict, and growing evidence confirms, that transgenes cannot dramatically accelerate plant breeding, let alone revolutionize agriculture, save the family farm or feed the world.

No Faster, Much Costlier

At the 55th Annual Corn and Sorghum Seed Research Conference held by the American Seed Trade Association in December of 2000, Drs. Major M. Goodman and Martin L. Carson of North Carolina State University added to the growing evidence that genetic engineering is much more expensive and less effective than plant breeding. They compared corn inbreds that have been produced by two methods: transgene insertion and hybridization between adapted and exotic germplasm.

Corn hybrids grown in the Midwest set new yield records almost every year. But Dr. Goodman has spent the past 25 years demonstrating that there remains much to be gained from the vast array of corn varieties grown across the tropics of Central and South America. He has used them to breed competitive, genetically diverse inbred lines adapted to the United States. His work is considered to be basic research with strictly long-term payoffs.

Goodman and Carson cite the example of NC296, an inbred line adapted to North Carolina but developed from all-tropical parentage. Released in 1990, it has been used to produce commercial hybrids in the United States and at least two other countries. NC296 took 15 years to develop—a long process, typical of breeding that uses exotic germplasm adapted to a different part of the world. It was five more years before hybrids having NC296 as a parent were being grown by farmers.

But compare that with the timetable for a *Bt* corn inbred that carries a bacterial transgene coding for an insecticidal toxin. According to Goodman and Carson,

> *Bacillus thuringiensis (Bt)* was used as an insecticide by the 1950s. The first gene encoding the *Bt* toxin was cloned by 1981 . . . *Bt* gene regulation was known by 1986 . . . *Bt* was [inserted] into corn in 1990 . . . *Bt* hybrids were first sold in 1997. Because *Bt* was a well-known entity with a long history of use as an 'organic' insecticide, little toxicity and allergenicity testing were required for its initial use as a transgene. Even so, its transgenic use took 17 years.

Of course, *Bt* was one of the very first transgenes commercialized. But while advances made in biotechnology over the past two decades may make gene discovery, cloning and transfer marginally faster, they cannot substitute for testcrossing and field testing. No matter how quickly one can carry out laboratory procedures, a certain number of plant generations are needed to accomplish any genetic manipulation, and the life cycles of crop plants can be speeded up only so much. Goodman and Carson list the steps that must occur before a transgenic corn inbred—with a truly novel gene, not just another version of *Bt*—can have its hybrid progeny tested in yield trials:

1. Discovery of the gene.
2. Modification, producing what is known as a 'construct' that can be transferred to a new species and, one hopes, perform as expected.
3. Efficacy testing.
4. Transformation of model species.
5. Construct comparison.
6. Transformation of maize plants.
7. Backcrossing the gene into the best inbred lines.

These steps occupy nine seasons, more or less. Then, the authors point out, at least as much time is needed to bring the gene to the farmer. That process includes testcrossing to a range of other inbreds, applying for experimental permits, 3 years of small-plot trials in different hybrid combinations, Environmental Protection Agency clearance, 2 years of large-plot trials, inbred and hybrid seed production, and sales. Even with the use of winter nurseries in the tropics to achieve two generations per year, and even if no unforeseen delays occur, Goodman and Carson estimate 15 years for development and deployment of a hybrid with a new transgene. This is only slightly shorter than the timetable for developing a hybrid from tropical germplasm through sexual methods—process that is considered to be long-term, basic research by most corn breeders.

But there is a big difference between the two methodologies: the transgenic hybrid costs at least 25 times as much to develop and release to farmers—28 times when the current $150,000 in federal permit and clearance fees are included. Table 1 shows itemized costs estimated by Goodman and Carson. Their million-dollar estimate for discovering a new gene is based on the assumption that discovery is 'a one-in–10–year event by a $100,000–a-year postdoc or equivalent (including salary and lab costs)'. In

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other words, they are assuming that for every ten postdocs or scientists searching for new genes to clone, one gene per year will be discovered and eventually utilized successfully. The authors don't estimate the number of postdocs and scientists worldwide engaged in such activity, but it is huge, with only a handful of commercially useful genes discovered to date. So Goodman and Carson's estimate assumes a steep decrease in future costs of gene discovery. The evolving science of genomics may or may not facilitate the search, but it cannot create genes. And there are not very many genes that, taken individually, will give major improvements in important traits.

One Gene versus Many

Even if genetic engineering does not speed up the breeding process, and even if it costs a lot more than sexual methods, it can, admittedly, produce plants with unique traits. *If* the new trait is one that improves the lot of the farmer, and *if* it gives us more or better food on our table, and *if* it protects or restores the rural environment, then something might be accomplished. But the only genes that have been deployed to date are ones that are expected to provide a return on investment for the companies holding patents on the genes or methodologies. There is growing evidence that they have not increased farmers' yields or profits, enhanced food quality or improved the environment. Indeed, transgenic technology—that is, single-gene technology—is not equipped to solve complex problems.

For decades, basic textbooks on plant breeding have included a section on backcross breeding, a traditional technique for moving a gene from Parent No. 1 into Parent No. 2, while keeping most of the other thousands of genes of Parent No. 1 intact. Sound familiar? Transgenic technology is just a high-tech form of backcross breeding, the only difference being that it can import genes from more distant branches of the evolutionary tree.

Table 1. Relative costs of development of an exotic inbred line versus a transgenic inbred line, as estimated by Goodman and Carson of North Carolina State University.

	Cost (US$)	
Step	**Exotic**	**Transgenic**
Choice of source/ discovery of gene	14,000	1,000,000
Breeding/modification	38,000	100,000
Efficacy testing		50,000
Transformation of model species		50,000
Construct comparisons		50,000
Maize transformation		50,000
Backcrossing		1200
Total	52,000	1,301,200

Textbooks also tell us that backcrossing is a useful *adjunct* t a breeding program, but that it is limited to producing update versions of yesterday's crop varieties—nothing truly new. A different sequence of techniques *has* been producing new cro varieties for over a century:

1. Development of diverse gene pools.
2. Recombination to shuffle the entire genetic deck.
3. Selection.

Sexual recombination in diverse crosses almost alway produces some offspring with unexpected expression of trait and unprecedented trait combinations. Breeders must so through large populations to identify progenies superior t either parent, but the effort is rewarded when unique tra combinations are identified and new varieties developed. Almos all new crop varieties, traditional or modern, have arisen fro cycles of hybridization and selection in diverse gene pools, wit widespread exchange of seeds, cuttings, tubers, etc. amon breeders. Without diversity, recombination and selectio breeding grinds to a halt.

The Sacrifice of Breeding Programs

Genetic engineering is not simply being superimposed o healthy, well-funded breeding programs; it is undermining them To understand how, consider the economic trade-off, based o Goodman and Carson's estimates. If it is to produce as man transgenic hybrids as non-transgenic, exotic ones, a breedin program requires a 28–fold increase in funding (and, even the the resulting hybrids would embody far less genetic diversity) That kind of increased investment is rare. More often, 28 no transgenic hybrids or varieties will be sacrificed to produce on transgenic product. Here, we should quote Goodman and Carso at length:

> Once the euphoria over the promise of transgenics fades, th closing of so many quality breeding programs, the loss o valuable sales staff, and the centralization of decision-makin at company headquarters are almost certain to be regarded a tragic, even by stockholders interested in short-term profit There are few good investments that are more long-term tha rational plant breeding. Repeated studies have shown tha very high returns on investment are available from expend tures on [non-transgenic] breeding . . . but the returns are n the instantaneous sort favored by the five-year funding pla currently in vogue. The usefulness of a breeding program probably more dependent on continuity than ingenuity. Th probability of great success by any one breeder is small, b the odds of success of a group of reasonably competen breeders working independently and continuously [and, might add, sharing seed] is high. At present, the evidence tha these same rules apply to biotechnology is almost nonexi tent.

The seas of corporate capital on which plant biotechnolog has floated for two decades will begin to dry up sooner later. Genetic engineering is following the trajectory of a the natural and technological wonders that have come an

gone in the history of plant breeding. Goodman and Carson listed some past 'bandwagons', just in corn breeding: mutagenesis, polyploidy, haploidy, overdominance, harvest index, high lysine, small tassels, nitrogen fixation, nitrate reductase and somaclonal variation, among others. The heyday of transgenes has lasted a bit longer than most, probably because of its patent potential and the flood of investment that it has brought. Like some of its predecessors, it eventually will find a niche as another tool available to plant breeders. But before its bandwagon rumbles off into the sunset, it will leave a trail of wreckage through our science, our rural environment and our food supply.

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Environmental Policies for Agricultural Pollution Control

Edited by **J S Shortle** and **D Abler**, *Department of Agricultural Economics* and *Rural Sociology, Pennsylvania State University, USA*

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Readership: Agricultural and environmental economics, environmental sciences research workers, advanced students, lecturers and policy makers.

This book describes the environmental problems associated with agriculture, particularly the use of pesticides and chemical fertilizers and the disposal of animal waste. These have become major policy issues in many countries, with the main polluting effect being on water quality. As with other types of pollution, significant reductions in agriculture's contribution to water pollution requires the application of either enforceable regulatory approaches or changes in the economic environment, so that farmers adopt environmentally-friendly production practices. Providing a review and guide to the policy options and their economic administrative and political merits, the reader can develop an understanding of these options and their merits in the emerging policy context. The principal focus is on the developed world, particularly North America and Europe. The book is aimed at advanced students, researchers and professionals in agricultural economics and policy, and environmental and pollution sciences.

Contents:
- Agriculture and Water Quality: the Issues, *J S Shortle and D G Abler, College of Agricultural Sciences, Pennsylvania State University, PA, USA*
- Environmental Instruments for Agriculture, *R D Horan, Michigan State University, East Lansing, MI, USA and J S Shortle*
- Voluntary and Indirect Approaches for Reducing Externalities and Satisfying Multiple Objectives, *R D Horan, M Ribaudo, Economic Research Service, Washington DC, USA and D G Abler*
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- Non-point Source Pollution Control Policy in the US, *M Ribaudo*
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Commentary

Moral confidence in agriculture

Robert L. Zimdahl

Abstract. *Those engaged in agriculture possess a definite but unexamined moral confidence or certainty about the correctnes of what they do. This paper examines the origins of that confidence and questions its continued validity. The paper argues tha those engaged in agriculture are morally confident about the rightness of their activity. The basis of the moral confidence is no obvious to those who possess it or to the public. In fact, the moral confidence that pervades agricultural practice is potentiall harmful because it is unexamined. Suggestions for expanding agriculture's moral scope are made to approach the question o where moral values originate, and what are, or ought to be, the moral standards for agriculture in our post-industrial, informa tion-age society. Part of expanding agriculture's moral scope will be giving up some of our hubris about the goodness of our cu ture and its agriculture. The paper advocates analysis of what it is about our agriculture and our society that thwarts or limi our aspirations for agriculture and needs modification. We must strive to nourish and strengthen those features of our agricultur that are beneficial and change those that are not. To fit ourselves to this task, we must be sufficiently confident to study ourselve and our institutions and dedicated to the task of modifying both.*

Key words: agricultural practice, moral scope, moral values

Introduction

Ethics is about what one ought to do. Ethical analysis involves analysis of what one does, and attempts to provide reasons to show why one's actions are the right thing to do. It must probe stated and unstated goals and the values presupposed by them. A good analysis will try to develop a rational way of deciding how an individual ought to live and how a profession ought to proceed toward realization of its goals (Singer, 1994). Such an analysis might lead one toward a set of 'rules, principles, or ways of thinking that guide, or claim authority to guide, the actions of a particular group' (Singer, 1994). It will make explicit what is valued and may lead to action on those values.

This paper argues that those engaged in agriculture, whether practitioners, research scientists, extension agents, technology developers or technology suppliers, share an unexamined moral confidence about the goodness of their activity. The paper also argues that the basis of that moral confidence is not obvious to those who have it or to those not involved in, but who may be curious about, agriculture and its technology. In fact, the moral confidence that pervades agricultural practice is potentially harmful because it is unexamined by most of its practitioners.

Perhaps the best that can be sought in the moral realm is not absolute certainty but the best available option, which many defenders of agricultural practice appear to believe i what we now have. We live in a world of moral ambiguity but it is also a world where some moral values seem to hav been accepted by all cultures (Kroeber and Kluckhoh 1952). No culture tolerates indiscriminate, harmful lying stealing or violence; incest is universally forbidden; n culture values suffering as a desirable goal; all cultures hav death rituals; protecting children is universally regarded a good in civilized societies; and all societies despise cow ardice and applaud bravery.

Even though there is moral certainty on these matters amon cultures, that same degree of moral certainty may not b desirable or achievable for the world's major environmenta interaction, i.e., agriculture. Because absolute moral certaint and the consequent lack of moral debate stifle discussion an progress, debate about what agriculture ought to do, rather tha agreement on what agriculture must do or be, is preferre Debate about morality should reveal the foundational theorie and values and thus provide a guide for action. Moral theorie are the, often invisible, foundation on which our judgments res Exploration of foundational theories will expose them to deba and discussion. When one understands the foundation of mor judgments, that understanding ought to lead to more confide judgments, but foundational values are not the answers t problems. They are ways to assist in constructing the persona social and cultural world we inhabit. Exploration of the mor confidence posited for agriculture will not reveal a sing guiding principle, the use of which will solve all moral dilemma in agriculture. It will reveal several principles that are used in th morally ambiguous, pluralistic world in which agriculture practiced.

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The benefits and costs of modern agriculture

Hugh Sidey, a contributing editor for Time magazine, delivered the 1998 Henry A. Wallace lecture to the Wallace Institute for Alternative Agriculture on 'The greatest story never told: the food miracle in America'. Sidey (1998) quotes Dumas Malone, a biographer of Thomas Jefferson, who said 'The greatness of this country was rooted in the fact that a single farmer could produce an abundance of food the likes of which the world had never seen or imagined, and so free the energies of countless others to do other things'.

US production agriculture: envy of the world

So much of recorded history is about the struggle of individuals and families to feed themselves. That changed dramatically in this country. Sidey contends that the story of the productivity and success of American agriculture is the greatest story never told. Few, if any, other segments of the American scientific–technological enterprise have amassed such an impressive record of predictive, explanatory and manipulative success over many years. American agriculture has been a productive marvel and is envied by many other societies where hunger rather than abundance dominates. Examination of yield records for nine major crops [corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), peanut (*Arachis hypogaea* L.), potato (*Solanum tuberosum* L.), rice (*Oryza sativa* L.), sorghum (*Sorghum biclor* (L.) Moench), soybean (*Glycine max* (L.) Merr.), tomato (*Lycopersicon esculentum*) and wheat (*Triticum aestivum* L.)] in the US during the 20th century shows that yield increases have varied from two- to sevenfold (Warren, 1998). No yields decreased. Scientific advances that led to these steady yield increases include development of higher-yielding cultivars, synthetic fertilizers, improved pest control, better soil management and mechanization. Warren (1998) suggested that the rate of yield increase does not appear to be slowing. Avery (1997) points out that without the yield increases that have occurred since 1960, the world would now require an additional 10 to 12 million square miles (roughly the land area of the US, the European Union countries and Brazil combined) for agriculture to achieve present levels of food production. Avery (1997) claims that modern high-yield agriculture is not one of the world's problems but rather the solution to providing sufficient food for all, sufficient land for wildlife and protecting the environment.

Questions and costs of social and environmental sustainability

American agricultural producers are proud of these achievements. Our food production system, including growing, distributing, processing and preparation, are now all part of a large, vertically integrated commercial system (Blatz, 1995). The family farm as an independent, self-supporting entity and a cultural icon is dying. The agricultural legacy that came from family farms and is the heart of the Jeffersonian agrarian tradition, that few Americans now experience but most value, no longer serves as an immediate, experiential source of societal values or moral sustenance. The abundant production that all involved in agriculture value highly is, in the view of Berry (1977), illusory, because 'it does not safeguard its producers, and in American agriculture it is now virtually the accepted rule that abundance will destroy its producers' and the land base. The evidence supports Berry's prediction. Stauber et al. (1995) provide census data that verify farm population decline from 1940 to 1990 in Iowa (72%), Minnesota (77%), Montana (74%) and North Dakota (82%). Stauber et al. (1995) also show that as farm population declined, farmland remained nearly constant because farm size increased in Iowa (88%), Minnesota (89%), Montana (121%) and North Dakota (123%). These trends were foreseen by Goldschmidt in 1947 and verified in his recent work (1998). He claims that 'large-scale, labor intensive, technologically innovative production made industrial farming possible but not necessary; social policies were needed for that'. The policies that made the decline of family farms inevitable were devised in a system where 'social relationships were money-based and social standing was money-driven'. The singular goal of the US agricultural system was 'to gain wealth, without the least concern for the welfare of those whose lives' were being destroyed. There was also no concern, or, at best, minimal concern, for the effects of the money-driven system on the environment, on which agriculture and life are dependent. The monetary rewards of the agricultural system are handsome for the survivors—profit. The social rewards of belonging to a caring community, the spiritual satisfaction of serving a larger public purpose, and the communities themselves and the businesses that they support have been sacrificed to the bottom line (Goldschmidt, 1998). These losses are the social costs of technological improvements in agriculture. They are neither necessary nor desirable. Goldschmidt (1998) argues that these losses are not trivial and should not be thought of as simply the inevitable price of progress. He argues that the changes in agriculture have made a big, and largely unnoticed, difference to our nation.

The highly productive agriculture that Sidey (1998) applauds, is a business like any other business, where producers seek high production at low cost. Each strives to adopt new technology rapidly to stay ahead of other producers and gain a competitive edge that leads to greater profit. The idea is not to work out ways for all to thrive, but to gain as much of the market and profit as possible so others cannot (Blatz, 1995). If a neighboring farmer's autonomy or survival is threatened by this system, it is not viewed as a systemic problem but as the neighbor's failure to adapt and survive. Agriculture has become industrialized not only in terms of its size and methods of operation, but in the values its practitioners espouse. The guiding purpose of each practitioner is to produce as much as possible at the lowest cost of capital and labor to generate maximum profit (Blatz, 1995). Much rhetoric is heard about the necessity and obligation of American farmers to feed the world. We also hear that keeping food costs low for consumers is a requirement of our system, in spite of the fact that both of these goods lead to the moral wrong that Berry (1977) deplores, the destruction of producers who care for each other and the destruction of the land. It is not

unreasonable to claim (Berry, 1977; Blatz, 1995; Jackson, 1980) that the highly productive American agricultural system is environmentally unsustainable at present levels of production.

At this point, many readers will assume that this paper will plead for a return to small-scale farming and for support of the possibly false claim of the moral virtue of family farmers and farming communities; and that the author, a Luddite (early 19th-century English workmen who advocated destruction of labor-saving machinery in protest for saving their jobs), wants to abandon the great achievements of scientific agriculture. On the contrary, the paper will suggest that the quantitative claims of US agricultural abundance are true. Sidey (1998) is correct. But blind acceptance of that fact may lead societies to assume that agricultural abundance is assured. No society can assume its agricultural abundance is assured, and the system that produces food should not be regarded as similar to a factory that, with the right inputs, can manufacture abundance at will (Blatz, 1995). Food is essential to life, but it comes from the land, not from money (Berry, 1999). Therefore the land that produces food is essential. If the foundational values of the food production system do not place protection of the land, the source of agricultural abundance, as an essential part of human life, and if food is regarded as another industrial commodity that can be purchased by those with money, then the ethics of the system ought to be a subject of societal concern.

It is common knowledge that the poor are hungry, even in the richest countries. It is a problem not amendable to an easy technical fix or social algorithm that will lead to its solution everywhere or quickly. In face of the undeniable success of agriculture in the developed world, its practitioners should at least ask the qualitative question about whether hunger is a problem of insufficient production, inequitable distribution or irresponsible consumption by the rich (Thompson, 1989). Many, certainly not all, agriculturalists often see more production as the solution, because they consider hunger to be only a problem of insufficient production (Avery, 1997). The other possibilities (inequitable distribution of abundance and overconsumption by the rich) are not considered or are readily dismissed.

As agriculture's productive capabilities have been enhanced by science-based technological discoveries, it is not surprising that the pursuit of production has conflicted with other societal values (Thompson, 1989). Any technology has effects in addition to those intended. For example, air in urban areas is polluted partially because of automotive exhaust: an unplanned effect. Similarly, agricultural technologies have undesired and often unanticipated effects (Thompson, 1989). Nitrates from fertilizer increase production and pollute water. New cropping techniques may expose soil to excessive erosion. Monoculture agriculture leads to loss of species diversity. Many technologies save labor, but what happens to the people whose jobs are lost is not considered. Pesticides increase production by limiting pest damage, but they pollute soil, air and water, and harm non-target species. New agricultural technologies have reduced the risk of production failure for producers but increased the risk of harm to other species, including humans. Advances in medicine and environmental science have made all of us more cognizant of risks that may have been unknown in the past (Thompson, 1989). Agricultural technology has always exposed people to risk. In the past most of the risk was borne by the user of the technology. Now many risks of agricultural technology are known, and it is known that they are borne by others. Technology developers, sellers, regulators and users, in their moral confidence, have not secured, or even considered, the importance of securing the public's consent to use production aids that expose people to involuntary risk. Thompson (1989) says:

> Agricultural producers and those who support them with technology may have been seduced into thinking that, so long as they increased food availability, they were exempt from the constant process of negotiating and renegotiating the moral bargain that is at the foundations of the modern democratic state. Democratic societies will not entrust their water, their diets, or their natural resources blindly into the hands of farmers, agribusiness firms, and agricultural scientists. Agricultural producers must participate in the dialogue that leads to social learning and social consensus about risks, and they must be willing to contribute the time and resources needed to understand the positions of their fellow citizens, and to make articulate statements of their own position.

For most non-agricultural segments of society, these are not new demands. For agriculture they are. Agriculture has been so confident of its narrow pursuit of increased production that its practitioners have frequently failed to listen to, and understand the position of others (e.g., environmental groups, modern agrarians, organic practitioners). Agriculturalists have not taken the time to articulate any value position other than the value of production and have not articulated the reasons that value ought to retain its primacy. Unintended consequences of agricultural technology are never just scientific or production questions. They always include a moral dimension that demands thought about fundamental values and the ethical foundation of those values.

Goals for Agriculture

Production of abundant food and fiber must remain a goal of agriculture. If agriculture does not produce, it fails to fulfill an essential goal of interest to all members of any society. When one asks what agriculture's goals ought to be, production must remain near the top of any list. However, because we live in a culturally pluralistic world, we are compelled to ask what other goals ought to be considered by agriculture, and when and why one or more of these may take precedence over production. Without describing all possible or desirable goals for agriculture it is possible, for purposes of discussion, to divide goals into two groups: social and environmental.

Social goals for agriculture

Proper social goals for agriculture were dealt with by Aiken (1984). He, like Day (1978), ranked profitable production as the primary goal of agriculture, a notion with which nearly all

agricultural practitioners would agree. However, Aiken (1984) then suggested sustainable production, environmentally safe production, meeting human needs and contributing to a just social order, as four additional goals, which may often be of greater moral importance than profitable production. This array diverges from the dominant agricultural view, and crucially that of Day (1978). Few agricultural voices speak of achieving a just social order. There is no inherent objection to a just social order, but it is not an agricultural goal. Thompson's analysis (Thompson, 1986) of Aiken's article (Aiken, 1984) ascribes the ranking to a straightforward principle for ordering of duties or rights: 'The principle would hold that one right or duty is more basic than another whenever the moral benefits associated with the second can be extended to all people only after the first has been protected or fulfilled.' Thus, 'a right to life is more basic than a right to an education'. One presumes that education is desired only by the living and that they must be fed, so the agricultural goal of production of sufficient food is not unreasonable.

Agriculturalists begin to diverge from others when discussion of sustainability occurs. Many in agriculture see sustainability as achievable by modification of the present system, and do not countenance abandoning the system that has been so successful. Achieving sustainability is regarded as a scientific matter. However, because agriculture is the largest and most widespread human interaction with the environment, achieving it also has social and ecological effects. Sustainability can be achieved best when the discussion includes consumers and producers (Thompson, 1986) and considers environmental effects. Thus, achieving a sustainable agricultural system is a societal not just an agricultural responsibility.

The agricultural market, as part of the greater market of all goods and services, distributes agricultural supplies to producers and produce to consumers. Markets are very powerful mechanisms, but they often are not just. If they were just, then America would not have hungry people. Those who emphasize the primacy of production must recognize the connection between what is produced, the market that distributes it and a just social system.

Thompson (1986) acknowledges the persistence of the agrarian ideal in the American mind. As family farms and rural communities disappear, the virtues they instilled in past generations (love thy neighbor, be kind to animals, help those in need, respect the family, respect your elders, etc.) are still valued by our society. Churches and schools try to teach these virtues, although schools are frequently chastised for teaching values. I suggest that most parents want children to learn what they regard as traditional values and they mourn their loss. We cannot figure out how or where to teach what used to be obtained by osmosis from the culture. Thompson (1986) suggests that one way to encourage these values is to have them 'prominently displayed in the social purpose of an economically central and vital activity such as agriculture'. To accomplish this, those in agriculture are going to have to abandon the singular pursuit of production as their only goal and incorporate the conscious pursuit of social goals as part of the practice of agriculture. This necessitates debating what the right goals are.

Environmental goals for agriculture

Environmental goals for agriculture should not be, and perhaps cannot be, divorced from social goals. Sustainability is regarded by those in agriculture as primarily a production and secondarily as an environmental goal, but others see it as a social goal. The view depends on what one wants to sustain. In agriculture, to sustain usually means to protect the productive resource base (soil and, more importantly, soil quality, water and gene pools) and maintain production. Others will agree that protecting these is important, but might rank protecting them below sustaining environmental quality, family farms, rural life, small businesses that serve agriculture, small communities, and a way of life that can only be achieved on the farm. This is not merely a semantic debate. It goes to the heart of what agriculture ought to do; what values it ought to espouse. Leopold (1947) addresses the essential issue regarding land when he suggests that the last great moral divide is between those who regard land as property that they own and can do with as they please and those who see land as part of the community to which they belong. Leopold (1947) based his land ethic on the absolute human need for community. We humans want to belong. In Leopold's view we need to protect the land so there will be a community left to which we can belong. Agriculture has a major responsibility because it has the potential to care for, or harm, so much land. This is a different view from protecting land only because it is a productive resource. Land, as Leopold (1947) claimed, is the basis of life. It is the necessary resource for a productive and profitable agriculture (Thompson, 1988). Without the land there will be no agriculture, so land must be regarded as something more than other productive resources (e.g., fertilizer, machines, irrigation water, pesticides or seed). Its importance to agriculture should not be thought of only in monetary terms. The ecological imperative of interconnectedness must be stressed more than a simple production ethic allows. To harm or destroy the land is not just a matter of profit and loss, because such actions destroy that which is essential to life, and that certainly raises a moral question.

The challenge and problem of social and environmental goals for agriculture are that they involve values as the defining characteristic of the questions raised. It is generally not recognized in agricultural science that values are not peripheral to the science and technology but are foundational (Capra, 1996). Scientists know they are responsible for the scientific integrity of their work and for its intellectual contribution. They do not as readily assume responsibility for moral aspects of their work, but it can be argued that they should.

Biotechnology, which has captured the university, State, and Federal research systems, is a good example. Just as pesticides were from the 1950s through the 1970s (Cate and Hinkle, 1993), biotechnology is now in its ascendancy. In the earlier era, massive resources were turned toward learning how to use pesticides to make agriculture more productive. Now the same institutions are turning from the talents of agronomists, chemists, entomologists, pathologists, toxicologists and weed scientists to the talents of molecular biologists and biochemists. In the first era, pest-management problems were solved through chemistry,

and now genetic engineering (genomics) is becoming dominant (Cate and Hinkle, 1993). However, agricultural systems are not products to be discovered, wrapped in a shiny package and sold. They are continually evolving toward changing goals and objectives. Effective management of any pest is fundamentally an exercise in applied ecology (Cate and Hinkle, 1993), which is not achieved by one more product from the genetic engineer or chemist. Neither group has the education, nor often the inclination, to address the ecological, social or moral questions that arise. The true social and environmental costs of any technology are rarely measured by the developer. They are not part of most profit and loss calculations, and many such costs are not even known, although all are paid by someone. Pesticide developers were alerted to ecological, social and moral questions by many authors (Carson, 1962; Murray, 1994; Perkins, 1982; Van Den Bosch, 1978; Wright, 1990). The current public controversy about genetically modified organisms has a familiar ring.

Anyone can dismiss any criticism of technology by saying 'Well, its not true for me'. This makes our personal beliefs, our assumptions, absolutely secure, and then there is no reason for beginning the difficult task of examining them (Melchert, 1995, p. 63). How any idea strikes us, especially one that is critical of our activity or profession, is not a reliable guide to how we ought to respond. Our first reaction, our intuition, may be mistaken. It is best to know and consider the arguments that support the idea or criticism. In science the data or theory that best explains the observations usually win. In ethics the best arguments win. It is indeed unwise to avoid the temptation to ignore good arguments that disagree with our assumptions. We may often find ourselves finding the truth we want; not by inventing it, but by allowing the emergence of only the part of the whole truth we want to hear (Barrow, 1995). When agriculturalists think of the future of agriculture, it is important that they recognize that their vision of the future (their truth) affects the decisions they make (Harman, 1976) and how they practice or recommend agriculture be practiced. The research and teaching we do now involves a view of a future we expect, desire or fear (Harman, 1976). If our view of the future changes, the decisions we make each day change. Our view moves from what is, to how we would like things to be, to what we perceive to be good. We then move quickly to a description of what we ought to do to achieve the good we desire. It is in this transition that we depart from the domain of science and enter the domain of evaluation, from which an ethic can be developed (Rolston, 1975). If the good we desire is inspiring, it will impel us and others to action. If our view is uninspiring or wrong, there may be no common image of what is worth striving for. Then a discipline or a profession will decline because it lacks an inspiring vision and adequate motivation.

Most of my colleagues in Land Grant University Colleges of Agriculture are confident that their research and teaching are morally correct. They defend their objective approach to science and their objectivity in defending agriculture and agricultural research against emotional attacks from people who don't understand either. I often hear 'People should not complain about our agricultural system with their mouth full' a conceit that dismisses the complaint without hearing it. The scientist' frequent appeal to the value of objectivity in science is evidenc of a lack of awareness of the inevitable subjectivity of science Niels Bohr, a pioneer in quantum mechanics, suggested th scientifically heretical idea that the mental decisions of th investigator influenced the outcome of an experiment. His poin was that observers create the reality observed (Shlain, 1998) This does not mean that there is no such thing as objectivity, o that all of science has to be discarded. It does mean that scienc has 'to admit its nemesis—subjectivity—into its calculations' No science, including agricultural science, is immune to th nemesis of subjectivity. For example, a study done of the faculty of the college of agriculture at Washington State University (Beus and Dunlap, 1992) showed that faculty members were slightly more in favor of conventional agriculture than farmers statewide were. They were slightly less conventional than proponents of conventional agriculture and far more conventional than known proponents of alternative agriculture. Beus and Dunlap (1992) also found that women, younger faculty, and faculty not raised on farms were somewhat more likely to endorse the alternative agriculture paradigm than their counterparts. These faculty groups have made a transition from the scientific to the ethical realm, perhaps without knowing they have changed. They moved quickly and easily from observation of what is, to knowing that it is good and ought to continue to occur (Rolston, 1975). The supporters of the status quo or conventional agricultural research direction and practice are morally confident of the rightness of their unexamined position.

An additional example is provided by a series of articles in the High Country News. Jones (1994) accuses land grant universities of having 'elevated efficiency and scale of production above all other values'. Their efforts have nearly eliminated the original land grant constituency of small family farms because rural people and the environment have not been central concerns. Jones (1994) suggests that this is because the faculty and administration are tightly connected with traditional rural interests, and faculty have lacked the freedom and encouragement to implement new ideas. She laments the lack of creative ideas flowing from land grant universities about such rural problems as land use planning in rural areas, grazing or logging. Land grant university faculty, in Jones' view, have handed over to others the intellectual oversight of major agricultural issues. As apologists for exploitive industries, land grant universities 'usually value the economic interests they serve above the public interest' (Wuerthner, 1994). Jones (1994) concluded that the institutions have been challenged and 'in their own, ponderous way, they are responding to that challenge'. As the Washington State University study (Beus and Dunlap, 1992) shows, younger faculty are aware of agriculture's problems and are dealing with them.

Expanding Agriculture's Moral Scope

To suggest expanding agriculture's moral scope is not to suggest that agriculture and its practitioners lack moral standards, or that all past achievements and values must be abandoned. It also does not suggest that this paper is about t

reveal a new, correct set of moral standards for agriculture that will solve the problems. Expanding the moral scope includes asking where moral values come from, and what are, or ought to be, the sources of moral values for agriculture.

The utilitarian standard

Agricultural research and agricultural policy have had an identifiable utilitarian ethical standard since inception (Thompson et al., 1991b). The clear emphasis on increasing production and reducing production cost to increase profit identifies the utilitarian ethical standard—to provide the greatest good for the greatest number—that has been implicit in agriculture (Thompson et al., 1991b). This standard, accepted and largely unexamined within agriculture, has assumed that increasing production and reducing cost will optimize the social benefit of agriculture. There has been almost no dialogue within agriculture about the correctness of the standard for all agricultural issues. One result has been that many scientists, ignorant of their own social context and all results of their technology, have, without questioning, accepted the loss of small farmers and rural communities as part of the necessary cost of achieving the greater goal of maintaining a cheap food supply (Stout and Thompson, 1991). The utilitarian standard is evaluated in terms of outcomes, and agriculturalists use easily observed outcomes to evaluate what they do. They measure total production, crop yield and profit (which, according to the USDA as reported in the New York Times (November 28, 1999), has decreased by 38% since 1997). They conclude that they are acting morally because good results have and, it is assumed, will continue to follow increased production. The morality of an act according to the utilitarian standard lies in its consequences, but it does not focus on intentions, as other moral standards (e.g., Deontological ethics) do. Thus, the cry for justice by the poor, or the pleas of those concerned about loss of environmental quality, are overwhelmed by the achievement of increased production and are often regarded as simply pusillanimous appeals.

Utilitarian thinking allows individual research scientists to believe that each research program is ethically correct because of its perceived good effects. Utilitarian standards are able to assign moral responsibility to any agricultural program or research area without considering the entire system (Thompson et al., 1991a). Agricultural scientists often see agriculture as a system of separable goods (e.g., seeds, bags of fertilizer, liters of pesticide, etc.) rather than as a unified system. This view is a result of our reductionist heritage. Agriculturalists have learned to deal with highly divisible technologies (separable goods) rather than with non-divisible systems (e.g., tractors, dams, irrigation systems) that usually demand a more holistic perspective.

None of the foregoing should be interpreted as an attack on the personal moral standards of individual scientists. I assume that anyone who has a research or teaching position knows the ethical norms (Holt, 1997). But as Ruttan (1991) has said, 'agricultural scientists have been reluctant revolutionaries'. They have wanted to change agricultural practice and results but have neglected the revolutionary effects of their efforts on society. They have believed that their work could be reduced to their little piece of agriculture, and then added without changing the whole system. Increasing production was the goal, and it was believed that could be accomplished without creating, or at least without out being bothered by the creation of other, revolutionary effects (Ruttan, 1991). The ethical standards Holt (1997) assumes operated only within the immediate confines of the scientific enterprise; all else was external and could, therefore, be neglected. Agricultural research is done in a morally narrow and ambiguous context, with little recognition of either.

The relevance of the Western agricultural model

The shift in the developed world, after the Second World War, to intensive farming systems with modern chemical and energy technology, led to major increases in plant and animal production. These systems maximized production through specialization, increased scale of production units, minimization of labor requirements and maximum use of technological inputs. They allowed Western nations to fulfill more adequately than any societies have before what Ponting (1991) calls 'the most important task in all human history': to find a way of extracting from the ecosystem enough resources to maintain life. The concomitant problem, in Ponting's view, is that human societies have had difficulty balancing their 'various demands against the ability of ecosystems to withstand the resulting pressures' (Ponting, 1991). Countries that employ intensive agricultural systems have met the needs and many of the wants of their citizens, a high value; but, in the view of many, they have made excessive, unsustainable demands on the ecosystem, which was less valued. We in the West use this story of success (Sidey, 1998) in meeting human needs to support our belief in the universal suitability of intensive agriculture.

Huntington (1996) proposes that 'this belief is expressed both descriptively and normatively'. Descriptively, agriculturalists believe that all societies want to adopt Western agricultural techniques to increase production. We also believe that others are willing to accept Western institutions and practices to achieve these good ends. If they seem 'not to have that desire and to be committed to their own traditional values, they are victims of a ''false consciousness'', e.g., failure to adopt genetically modified seed. Normatively, the Western agriculturalist proposes that all societies ought to adopt our methods, institutions and the associated values, because they embody 'the highest most enlightened, most liberal, most rational, most modern, and most civilized thinking of humankind'. Huntington (1996) says that belief in the universality of Western values and culture suffers from three problems: 'it is false, it is immoral, and it is dangerous'. In looking at other cultures with Western lenses and assumptions about what is good, we make the further error of assuming we are learning about what other people's conceptions of the world are, rather than observing how the world really is. Only we understand how the world really is and, therefore, we assume we know how agriculture ought to be practiced. Thus, part of expanding agriculture's moral scope will be to give up some of our hubris about the moral correctness and value of our culture and its agriculture.

Bottom-line thinking

Goldschmidt (1998) claims that the singular goal or 'bottom-line' of our agricultural system was 'to gain wealth, without the least concern for the welfare of those whose lives' were being destroyed. There was little thought about the effects of the money-driven system on the environment. The social rewards of belonging to a caring community, the spiritual satisfaction of serving a larger public purpose, and the communities themselves and the businesses that they need and support have been sacrificed to the bottom line (Goldschmidt, 1998). Convenience, ready availability and low cost are not the only things that matter. There are other things that are important, such as the presence of local businesses, friendliness, service, the essentiality of business to any community's survival and local employment opportunities, and if large-scale farming eliminates or harms these things, then perhaps we should think again about the importance of the bottom line. The losses Goldschmidt (1998) speaks of are the social costs of technological changes in agriculture. In agriculture, bottom-line thinking is the norm and may be part of the hubris we must reconsider if we are serious about our communities, and our agriculture.

Sustainability

As we reconsider our hubris and the bottom line, there will inevitably be conflicting interests that arise from opposing world views, incompatible analyses based on different views of the nature of the problem, rising material expectations and different views of sustainability (Allen, 1993). Few oppose sustainability, but there are many different views of what ought to be sustained. Expanding agriculture's moral scope requires that we give up the common two-track agricultural defense used when issues ranging from pesticides to sustainability and loss of small farms to animal treatment are raised. The first track has been to deny that the suggested problem exists (e.g., pesticides don't harm people or wildlife, people who use them incorrectly do; and the loss of small farms is unfortunate but it is an economic not an agricultural matter). The second defense has been to explain, calmly but forcefully, that the reforms advocated (e.g., reductions in pesticide use, maintenance of small farms, humane animal treatment) will make food too expensive and diminish or eliminate the favorable balance of trade the US enjoys from its agricultural surplus. The argument claims that the public will not tolerate higher food costs to save a few small, inefficient farms; the reforms would surely diminish or eliminate the trade surplus; and neither is politically acceptable.

Expanding agriculture's moral scope demands considering challenging views of agricultural practice. For example, Ludwig et al. (1993) posit a 'remarkable consistency in the history of resource exploitation: resources are inevitably over exploited, often to the point of collapse or extinction'. The view is shared by Berry (1977), Jackson (1980), Ponting (1991) and other commentators on modern agriculture. Ludwig et al. (1993) suggest that wealth, or the prospect of wealth, generates social and political power that is used to promote unlimited exploitation of a resource. Exploitation of land and farm communities are good examples. Scientific understanding is hampered by lack of controls, and the natural variability that is expressed on large scale makes detection of effects very difficult. Th complexity of large agricultural systems encourages a reduc tionist approach that precludes observation of large-scale effect In the view of Ludwig et al. (1993), the long-term outcome is heavily subsidized industry that overharvests the resource. Tha is an accurate description of modern agricultural practice Ludwig et al. (1993) suggest that sustainable exploitation always preceded by overexploitation. If they are correct, the agricultural sustainability will not be achieved by adjustments t the present system. Experience over 3000 years, documented b Ponting (1991) and cited by Ludwig et al. (1993), suggests tha good scientific understanding of exploitation, its causes and th appropriate prophylactic measures is not sufficient to preven destruction of the vital resource. It is a sobering commentary tha must be considered and addressed by the agricultural communit and the larger society in the quest for sustainability.

Kirschenmann and Youngberg (1997) understand the com plexity of agriculture's striving for sustainability. They acknowl edge that those involved in the discussion must conside biotechnology, continuing agricultural industrialization, publi concern about food quality and safety, pesticide use and abuse rural community deterioration, worker welfare, internationa trade, global competitiveness, farmland preservation, wildlif and habitat protection, public funding of agricultural researc and extension programs, natural resource conservation, and hov to identify, and somehow include, what have been externa agricultural costs. None of these are simple issues Kirschenmann and Youngberg (1997) believe that agricultur will develop along two paths. The first will be 'larger, highl specialized, vertically integrated farms' with efficient inpu management and precision farming techniques. The second wi be 'small, intensively managed, diversified operations' with lo input and an emphasis on sustainability. Many of the latter wi emphasize organic production methods (see also den Hond et al 1999). The two paths are not necessarily heading in opposit directions and should not be viewed as conflicting agricultura futures. Kirschenmann and Youngberg (1997) forecast tha biotechnology will be the primary force that shapes tomorrow' agriculture, and that water quality will be the major enviro mental issue. There will be increased reliance on export market to sustain grower profitability, while the primary concern c consumers will be food safety. There will be a resurgence c rural communities near cities but a continued, slow demise c isolated rural communities. Development of sustainable agr culture will be emphasized, but there will be a decreasing leve of public support for agricultural research in publicly supporte agricultural institutions.

Conclusions

Agricultural scientists share with other scientists a passion fo the truth. We hold the Socratic belief that the search for the trut is the very best way of life (Melchert, 1995, p. 452). We e when we engage in distorting the truth by hiding it fro ourselves or pretending that it is other than what we know it i We tend toward that mistake when we think that what has r

price has no value, that what cannot be sold is not real, and that the only way to make something actual is to place it on the market (Merton, 1960). Merton tells us that bottom-line thinking cannot answer all questions. Small-scale farmers may be necessary to care for the land, our most precious resource; small communities may be important to our national and personal character. Neither is susceptible to pure economic analysis. Merton (1960) also deplores in strong, environmental language 'constructing a world outside the world, against the world, a world of mechanical fictions which contemn nature and seek only to use it up, thus preventing it from renewing itself and man'. Strong environmental criticism is not foreign to agriculture, but it is not valued as a means to seek the truth about agriculture.

As agriculture searches for an ethical standard, while being compelled to deal with criticism of its apparent bottom-line standard and the environmental problems that have followed modern agricultural practices, one must ask, as Holt (1997) has, 'How do we find our way?' Holt's answer comes in the context of his concern that 'if there are no revealed truths, immutable principles, or even practical, utilitarian generalities, such as the importance of honesty and integrity, that apply to science, how can we determine what constitutes ethical behavior?' When there are no points of reference, no moral certainty, in 'a sea of uncertainty', how can one make ethical judgments? Holt's answer is bottom-line thinking and apparently utilitarian. He argues that in the global marketplace of which agriculture is now a part, 'the question of whether it is ethical to conduct research on certain subjects, including products or services that might do harm to the environment or make food unsafe, e.g., chemicals, is moot. The need for effective pest control will be so great that no options can be precluded before research reveals the potentials.' He goes on to suggest that research on technology that might cause dislocations (a locution that avoids the unpleasant connotation of suffering) of small farmers is also moot. Market-oriented economies and diminished government interference in agriculture will 'assure that less efficient and productive practitioners will be dislocated'. Holt's (1997) concluding message for agricultural scientists is quoted in full below.

> I think there is an important message for agronomists and other agricultural researchers and research administrators in this analysis of driving forces. It says that as you plan and implement research on the environment, natural resources, safety, social issues, or other themes, keep it within the context of quality, productivity, and efficiency. In order for any technology or information generated in that research to find fruition in practice, it will have to contribute to quality, productivity, or efficiency or at least not detract from them.

Holt (1997) believes that the 'broadly focused ethical debates of the past' are also moot. His view is consistent with Day's view that agriculture has only one proper goal: profitable production (Day, 1978). This view ignores the necessity of balancing the often conflicting goals of profitable production and environmental quality, or the loss of small farms and the rise of corporate agriculture. Agriculture's continuing problems with pollution by pesticides and nitrates, animal welfare, soil erosion, loss of genetic diversity, genetic modification of plants and animals, and food safety are all swept under the carpet of profitable production that makes all other arguments moot. To be moot is, first, to be open to discussion or debate, to be debatable, and, second, to be so hypothetical as to be meaningless. It is the latter definition that Holt (1997) uses, and I fear it is the view shared by most in agriculture. It is a view that claims 'we are doing the most ethical thing of all, feeding the world and when you are hungry you will recognize the wisdom and rightness of our actions and methods'. The view dismisses the cries for justice, environmental quality or food safety as pusillanimous appeals that are moot.

In Holt's view there is no compelling moral argument for saving family farms, because of the economic realities of the global market within which agriculture must operate (Holt, 1997). Wendell Berry (1977) and others who argue for preservation of family farms, on the basis of a Jeffersonian agrarian appeal about the virtue of the small farm and how it was and remains the basis of our civilization, obviously, just don't understand the modern world.

I conclude that while agricultural scientists are ethical in the conduct of their science (they don't cheat, don't fake data, etc.) and in their personal lives (they earn their wages, take care of family, are responsible for their actions, etc.), they do not extend ethics into their work at a deeper level. Agricultural scientists are the reluctant revolutionaries that Ruttan (1991) identified, but they are also realists. Realists run agricultural research and the world; idealists like Berry and Jackson do not. Idealists attend academic conferences and write thoughtful articles and books from the sidelines (Kaplan, 1999). The action is elsewhere. The rule is produce profitably or perish in the real agricultural world. Realism rules, and philosophical and ethical correctness are no more necessary for useful work in science than theological correctness is in religion (Rorty, 1999).

I find that true, but I want more. I want my colleagues to accept the burden of beginning the difficult task of doing a discriminating cultural and moral analysis of agriculture and its results. We must strive for a careful analysis of what it is about our agriculture and our society that thwarts or limits our aspirations and needs modification. That analysis must include the work of the US Department of Agriculture, agricultural colleges, scientific societies and the many commercial organizations that serve and profit from agriculture. We must nourish and strengthen those features that are beneficial, and change those that are not. To fit ourselves for this task, we must be sufficiently confident to study ourselves and our institutions, and dedicated to the task of modifying both. It takes a combination of intellectual rigor and management skill to do this well. Management skill is required but difficult to achieve. Intellectual rigor annoys people because it interferes with the pleasure they derive from allowing their wishes to be the father of their thoughts (Will, 1999).

To preserve what is best about modern agriculture, and to identify and oppose the abuses that modern technology has

wrought on our land, our people and other creatures, and finally to begin to correct them, will require many lifetimes of work (Berry, 1999). We agriculturalists must try to see agriculture in its many guises—environmental, economic, political, productive, scientific, social and moral. It is no longer sufficient to justify all agricultural activities on the basis of increased production. Other criteria, many with a clear moral foundation, must be included. We live in a post-industrial, information-age society, but we do not, and no one ever will, live in a post-agricultural society. Societies have an agricultural foundation within their borders or in other countries. Those in agriculture must strive to assure all that the foundation is secure.

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Evaluating Indirect Ecological Effects of Biological Control

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